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REVIEW OF TREATMENT TECHNOLOGY IN THE FRUIT AND
VEGETABLE PROCESSING INDUSTRY IN CANADA, 1977.

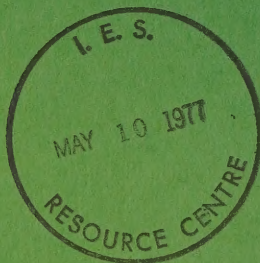
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Review of Treatment Technology in the Fruit and Vegetable Processing Industry in Canada



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Report EPS 3-WP-77-5

—Water Pollution Control Directorate
March 1977

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REVIEW OF TREATMENT TECHNOLOGY IN THE
FRUIT AND VEGETABLE PROCESSING INDUSTRY
IN CANADA

by

Stanley Associates Engineering Ltd.

for the

Abatement and Compliance Branch
Water Pollution Control Directorate
Environmental Protection Service
FISHERIES AND ENVIRONMENT CANADA

Report No. EPS 3-WP-77-5
March 1977

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ABSTRACT

This report is a review of the state-of-the-art of wastewater treatment in the Canadian fruit and vegetable industry. The findings are based on data from eight plants and are not an inventory of Canadian processing plants.

Because the fruit and vegetable industry is both wide ranging and complex, 11 major commodities were designated for study. Additionally, investigators used much available data from U.S. sources where a data bank on 650 processing plants exists. Only data which were pertinent to the Canadian scene were used.

Current technology and treatment practices were found to be very similar in both countries but spray irrigation treatment is more costly in Canada as climatic conditions generally require winter storage facilities. Other treatment methods include screening, sedimentation, flotation and biological treatment. Available U.S. and Canadian technology should produce a reduction of BOD_5 and suspended solids greater than 90%. However, where receiving streams are small, even 90% reductions may not be sufficient, making polishing or land applications necessary.

This report found that the BOD_5 levels of the wastewaters discharged by the Canadian industry were generally high with a great potential for oxygen depletion in receiving waters.

RÉSUMÉ

Le présent rapport expose l'état des connaissances sur le traitement des eaux usées dans l'industrie de préparation des fruits et légumes au Canada. Les résultats se fondent sur les données provenant de huit usines, mais n'évaluent pas la situation de l'ensemble de cette industrie au pays.

La préparation est très complexe et englobe une vaste gamme de produits; aux fins de l'étude, nous en avons donc choisi 11 parmi les plus importants. En outre, nous avons abondamment puisé à une banque de données sur 650 usines de cette catégorie aux États-Unis; toutefois nous n'avons retenu que les données s'appliquant à l'industrie canadienne.

Les techniques et les pratiques de traitement de ces eaux usées sont très semblables dans les deux pays; cependant, l'arrosage qu'on peut en faire est beaucoup plus coûteux au Canada où les conditions climatiques imposent habituellement de les entreposer pendant l'hiver. Les autres méthodes de traitement sont le tamisage, la décantation, la flottation et l'épuration biologique. Les techniques connues tant aux États-Unis qu'au Canada devraient amener une réduction de plus de 90 p. 100 de la DOB_5 et des substances en suspension. Cependant, ce niveau d'efficacité peut se révéler inadéquat si les eaux réceptrices sont peu abondantes; il se peut alors qu'on ait à recourir à une épuration plus poussée ou à l'épandage.

Nous avons constaté, dans les effluents de l'industrie canadienne, un niveau généralement élevé de DOB_5 , qui peut lourdement affecter le taux d'oxygène des eaux réceptrices.

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SYNOPSIS

A review of the state-of-the-art of wastewater treatment technology in the fruit and vegetable industry was carried out. Based on information contained in this study and supplemented by information from a number of Canadian plants, conclusions can be drawn with respect to the following:

- wastewater quality
- wastewater treatment technology
- Canadian operations
- degree of treatment.

Wastewater Quality

A number of general conclusions can be drawn regarding the quality of wastewater from plants in the fruit and vegetable processing industry.

1. The levels of organic strength (BOD_5) are generally high and consequently there is a great potential for depleting oxygen in receiving streams.
2. The levels of settleable and non-filterable suspended solids may be high, depending on the commodity processed.
3. pH values range from 4 - 12, depending on the commodity processed and the unit processes utilized.
4. Raw wastewaters are generally acutely toxic.

Wastewater Treatment Technology

Available treatment technology consists of the following:

1. Screening and solids recovery.
2. Primary sedimentation or flotation for commodities with high concentrations of suspended settleable solids, such as corn and beet wastes, or when soil particles are contained in the wastewater.
3. Biological treatment to remove biodegradable organics by the following: aerobic lagoons,
aerated lagoons,
activated sludge (extended aeration).

Fruit and vegetable wastes are highly biodegradable and can be treated, utilizing the same technology as is used for domestic wastewater treatment. However, since the strength of the waste is usually an order of magnitude higher than domestic sewage, it is necessary to establish design criteria based upon pilot plant investigations.

In many cases there is insufficient nitrogen and phosphorus present in the waste streams to provide optimum conditions for biological growth. It is therefore necessary to provide nitrogen and/or phosphorus addition in the BOD:N:P ratio which is optimum for a particular commodity process waste.

Combinations of aerated, anaerobic and aerobic ponds are common in the industry.

An alternative to biological treatment is the application of pre-screened and settled wastewater to land by spray irrigation; this is standard practice in approximately 50% of the U.S. industry. Where sufficient land is available, this alternative has an added advantage: it eliminates the direct discharge of the residual organics which usually occurs in biological treatment.

Spray irrigation systems require that extensive investigations of soil type and permeability, potential cover crops, subsurface strata, and runoff potential be carried out prior to application of a full scale system.

Canadian Operations

Investigations limited to a cross section of Canadian plants show that the available technology, as currently practised in this country, is very similar to that of the United States:

- i.e. screening,
- sedimentation or flotation,
- biological treatment.

Biological treatment systems utilized are aerated lagoons, extended aeration - activated sludge, oxidation ditch, and holding ponds.

Spray irrigation is more costly to construct and operate in Canada than in the warmer areas of the United States because of the requirement for storage during the winter period (up to seven or eight months, depending on location). However, it is an attractive alternative and used in Canada where sufficient suitable land is available in close proximity to the waste source.

Degree of Treatment

The degree of treatment provided at the Canadian plants is comparable to that in the United States and therefore available technology should reduce BOD_5 and suspended solids by more than 90%. In many situations where fruit and vegetable processing operations are located on small streams, the 90% reduction may not provide adequate protection of the water quality and aquatic habitat. In these instances, polishing treatment, or land application would be required.

1. INTRODUCTION

1.1 Background

The fruit and vegetable processing industry is characterized by the diversity of products processed and the seasonal nature of production. The industry is supply-oriented, due mainly to the perishable nature of the raw feedstock, with processing plants being located predominantly in the major fruit and vegetable farming areas. Plant sizes range from very small, employing a few persons, to very large, employing hundreds; fruit and vegetable processing organizations range from cooperatives through proprietorships and private companies to major corporations. A given plant's economic health is affected by many variables, including the vagaries of weather and supply of fruit and vegetables, the percentage efficiency in utilization of the raw material, the usual manufacturing operating cost factors, the changing demand pattern, and many others.

Fruit and vegetable processing operations are the source of a concentrated biologically-active effluent and highly putrescible solid wastes which must be treated and ultimately discharged to the land surface or a water body. Stringent control measures are likely to be required in many cases to avoid overloading the local assimilation capacity, while in other cases much less stringent controls would be appropriate. An objective of regulatory agencies is to establish rational effluent standards which will prevent pollution by fruit and vegetable processing wastes, yet which will represent practical, attainable goals. The costs of alternative abatement strategies must be carefully evaluated as these will either be passed directly to the consumer or, if this is prevented by competitive forces, may threaten the continued economic operation of the facility.

In recent years there has been a growing awareness of environmental issues by Canadians. The Federal Government responded to this public concern by putting forward a major legislative program, the focal point of which was the Government Organization Act resulting in the formation of a Department of Environment in June 1971. The Environmental Protection Service (EPS) was developed to cover the specific responsibility for environmental protection. The role of the EPS is one of problem identification and solution, being concerned with the control and abatement of pollution by formulating a realistic program of pollution control for Canada in cooperation with provincial authorities and industries concerned.

The approach of the Environmental Protection Service to pollution control is to adopt a strategy of containment at source by means of the best practicable technology. The regulations and guidelines developed to achieve this strategy are based on control methods which are the best from both an economic and environmental standpoint. Every effort is made to ensure the fullest participation of provinces and industries concerned, the first steps being to identify the problem in terms of an environmental inventory of the industry and to conduct a "state-of-the-art" review including waste characterizations, and process and waste treatment technologies. A Federal/Provincial/Industrial task force assesses this information and recommends the best practicable in-process and treatment technology on which to base effluent regulations or guidelines. These regulations or guidelines, as formulated by the Environmental Protection Service, are subsequently reviewed with the provincial pollution control agencies, the appropriate Canadian industry associations and international experts in the field with the objective of obtaining a general consensus on the soundness of the regulations or guidelines.

1.2 Scope

This report is one stage in the establishment of effluent standards, and has as its objective:

"To provide a state-of-the-art review of available control and treatment technology that may effect a decrease in waste loads in the Canadian industry.

The review would include:

- waste control through the use of new process technology and techniques or modification of existing process methods.
- wastewater treatment through use of new treatment technology or modification of existing treatment facilities."

For the purposes of this study, the fruit and vegetable industry included those establishments categorized within the Canadian Standard Industrial Classification No. 103. This classification defines plants in the fruit and vegetable processing industry as those:

"establishments primarily engaged in processing fruits and vegetables. Important products of this industry are: Canned, frozen or otherwise preserved fruits and vegetables, vegetable and fruit juices, soups, pickles, jams, jellies, marmalades, ciders, sauces and vinegars."

The potato processing and sugar beet processing industries were not included within the context of this study.

It should be emphasized that this report is not an inventory of Canadian plants. The analysis and conclusions regarding the operations of the industry in Canada have been based largely on data obtained from eight plants. The representative nature of this group of plants with respect to product mix, production rate, and in-process and treatment technology is not known at the present time. An inventory of Canadian plants in the industry was being initiated; however, the results were not collected in time for incorporation into this state-of-the-art review.

In assessing the available information from the United States, major consideration was given to those food products which are generally common to the Canadian fruit and vegetable processing industry.

In this report, the metric system of units has been used for the presentation of data. Production rates are expressed in metric tonnes (t) and wastewater flow rates in cubic metres per day (m^3/day). Effluent parameter concentrations are expressed as milligrammes per litre (mg/l) and unit waste loadings as kilogrammes per metric tonne (kg/t). Conversion factors to the English system of units (tons, pounds, gallons, etc.) are given in Appendix I.

1.3 Approach

Details of data sources that were used to develop the state-of-the-art review of the fruit and vegetable industry are given in Section 2 of this report. The prime sources of data and information were the sampling and analysis program carried out at a number of Canadian plants and specialized input from Environmental Associates, Inc. supplemented with other literature and data sources. These data and technical information were analysed and compiled to evaluate the industrial processes (Section 3), and in-plant and end-of-pipe treatment technology (Sections 4 and 5, respectively).

Data and information from the plant surveys and additional information from the companies concerned and other Canadian sources, were used to determine wastewater characteristics of Canadian plants (Section 7).

An assessment was made of existing technology for the attainment of specific levels of water quality. Constraints on the attainment of these levels of quality were also considered.

In carrying out this project, Stanley Associates Engineering Ltd. was assisted by Environmental Associates, Inc.; a firm which has carried out extensive work on the development of effluent guidelines applicable to the U.S. fruit and vegetable processing industry for the U.S. Environmental Protection Agency. As a result of this work, they have compiled an extensive data bank of information on approximately 650 fruit and vegetable processing plants in the United States. Much of the information possessed by Environmental Associates, Inc., has proven useful to this study, including the following:

- unit raw waste loadings and final effluent loadings for specific types of operations to augment to acquired Canadian data base;
- extensive information (including costs) on waste management techniques and waste treatment systems applicable to the Canadian industry.

2. DATA SOURCES

Prime sources of data for plants in the Canadian fruit and vegetable processing industry were those individual plants at which surveys were carried out during the course of the study. The purpose of the surveys was to obtain pertinent data and information in accordance with the following terms of reference:

1. To identify the sources of waste discharge, and the characteristics of the wastewaters in the Canadian fruit and vegetable processing plants.
2. To identify and describe operational techniques and in-plant control technology which are being used within Canadian industry to reduce discharge of wastes.
3. To provide information on existing Canadian wastewater treatment technology.

With respect to the individual sampling and analysis program carried out at each plant, wastewater analysis was carried out in-house, and toxicity analyses were carried out either by EVS Consultants Ltd., Coquitlam, British Columbia or Enviroclean Ltd., London, Ontario depending on plant location. Information on plant processes, wastewater treatment systems and other analysis data was obtained from these plants to supplement data obtained from the sampling and analysis program.

The information on the operation of the Canadian industry was supplemented by input from Environmental Associates, Inc. who produced a document for Stanley Associates Engineering Ltd. outlining pertinent information on the U.S. fruit and vegetable processing industry. This information included characterization of wastewaters, descriptions of unit processes, in-plant process waste control technology and end-of-pipe treatment technology. In addition, raw waste loadings and other miscellaneous information on the major and minor fruit and vegetable commodities, pertinent to the Canadian scene, were included. This document also discussed the use of end-of-pipe treated wastewater. Data sources utilized by Environmental Associates, Inc. included published literature and files obtained through their involvement as a subcontractor to SCS Consulting Engineers, Inc. to prepare the Draft Document for Effluent

Limitations Guidelines, New Source Performance Standards for the Canned and Preserved Fruits and Vegetables Including Point Source Category, Phase II. It is considered that the data obtained from Environmental Associates, Inc. are more extensive than those presented in Reference 2 because of their subsequent work in connection with the fruit and vegetable industry.

The principal data sources discussed above were supplemented by literature and recent documentation made available for this study through the cooperation of the U.S. Environmental Protection Agency.

3. FUNDAMENTAL PROCESS DESCRIPTIONS

3.1 Introduction

General process descriptions and processes specifically for major commodities produced in the fruit and vegetable processing industry in Canada are included in this section. The sources of wastes are itemized and characterized where possible, including unit wastes loadings and water usages.

In this report, "end-of-pipe treatment" is used to signify waste treatment systems which are external to the processing plant. The term "in-plant waste streams" refers to those processing streams, either liquid or solid, which originate from one of the processing steps and which are collected prior to disposal to a waste treatment system or collected as solid material.

It is again emphasized that the metric system of units is used in discussing production rates, waste loadings, wastewater flows, etc. and reference is made to Appendix I for conversion factors to the English system of units.

3.2 General Process Description

It is recognized that the fruit and vegetable industry is complex so, for the purpose of this study, 11 major commodities have been designated. In order to simplify the descriptions of the individual processes used in the production of these commodities, a number of process techniques common to many of the categories of product are now described.

3.2.1 Harvest and delivery

Mechanical harvesting techniques are used in the collection of many of the commodities processed in Canada, including peas, beans, corn, tomatoes, cherries, beets, and carrots; much of the unusable material is retained on the field. Although mechanical harvesting is beneficial from an economic point of view, a recent report issued by the National Cannery Association [1] indicates there may be undesirable side effects such as greater physical damage to the crop, inclusion of soil and associated microbes, and loss in product yield associated with non-optimum commodity maturity and non-selective harvesting. Produce which is physically damaged

may become the location of microbial activity, resulting in rotting and consequent product downgrading.

In-field techniques may be used for a number of commodities including, for example, peas. The peas can be harvested mechanically, using a mobile viner which picks up the vines, threshes out the pea pods and shells the peas. The peas are loaded directly into trucks for shipment to the food processing plant. There are a number of advantages to this process, including the selection of optimum maturity, elimination of damage and solid loss during transportation, and the reduction in associated solid wastes from the fields. Separated wastes can be retained for ploughing into the ground.

Harvested commodities require transport to the processing plant and this is generally accomplished by the direct transfer from mechanical harvesters into dry bulk loading trucks and tote boxes. Certain commodities such as cherries, and tomatoes have been transported in water on an experimental basis [1]; this mode may provide economic advantages and ease of transfer at the processing plant. The effect on the commodity, the control of microbial growth, and economics need to be taken into account in considering this mode of transportation.

The product is generally delivered to the plant in containers of different sizes, including bulk shipments. Recent developments include the utilization of water to bulk flood tomatoes at the plant and to flume them from the container to the processing facility.

3.2.2 Washing and rinsing

Water is used extensively in conveying fruit and vegetables within the processing plants because of economic considerations and because of its combined use for washing and cooling as well as transportation. It has been generally assumed that the use of large quantities of water within the processing system permits the maintenance of sanitary conditions; the comparison of effectiveness of washing to reduce extraneous contamination given in reference [1] shows significant reductions in bacterial spores, bacteria, and other organic debris.

A significant disadvantage in the use of large quantities of water for the washing and rinsing operations (up to 50% of the total usage) arises from the leaching of biodegradable, soluble organic compounds such as sugars,

acids and starches. These organic materials increase significantly the organic and hydraulic loading on a given waste treatment system associated with a processing operation.

3.2.3 Peeling

Many fruits and vegetables are peeled prior to processing in order to remove undesirable peels, residual soil and pesticide residues. Methods used include mechanical cutting operations, application of steam, hot water or heated air. Caustic soda (lye solution) is used to soften the peel in order to remove it by high pressure water sprays or by mechanical methods such as rubber disks.

The caustic soda solution used for chemical peeling ranges in strength from 1% to 18% depending upon the nature of the skin. The lye solution temperature and contact time determines the concentration required; the residence time in the hot caustic bath may be three to five minutes, followed by a period of two to five minutes, during which the product is held dry, prior to removal of the loosened peels.

"Dry caustic" peeling is used for commodities such as tomatoes, carrots, beets and peaches. The process is similar to the wet caustic peeling method, the only difference being the method of peel removal. In the wet process, high pressure water sprays are used to remove the peel. In the "dry method, the peel is mechanically removed by rotating rubber "fingers" in the form of a thick slurry which is segregated from the process wastewater. The peel residue may be handled as a solid waste to avoid contamination with the normal plant wastewater stream.

3.4 Blanching

Vegetables are blanched prior to canning, freezing or dehydration for a number of reasons including (a) the removal of air from tissues, (b) the removal of soluble components which may affect the clarity of the liquid used in the canning process, and (c) fixation of the pigments. The inactivation of enzymes and destruction of microorganisms, in addition to the leaching of desirable flavours, permit the quality of the product to be preserved. Inactivation of enzymes is important in the freezing and dehydration process in order to prolong shelf life.

Blanching, using water, may be carried out in a number of different ways, the most common method being to convey the vegetable through a tank half filled with water heated to 65-100°C. The product is continuously fed onto the mesh conveyor at such a rate that the product is totally submerged; residence times vary with the type of end product and the vegetable being processed. Alternative methods for transporting the product through the hot water may be by the use of a pipe arrangement, as in the case of peas or diced carrots, or a screw conveyor system as in the case of dry beans.

Steam blanching is generally carried out in an elongated stainless steel tank into which steam is injected. The length of the tank, the depth of product within the tank, and the speed of the conveyor passing through the tank control the extent of blanching.

It should be pointed out that blanching with water removes more soluble organic material than that using steam, resulting in a higher pollutant loading. In some instances, this pollutant load may be a significant portion of the total loading.

3.2.5 Clean-up

Clean-up operations vary widely from plant to plant and from product to product. Normally the plant and equipment is cleaned at the end of a shift, generally by washing down equipment and floor with water. The quantity of water used in the clean-up process can contribute significantly to the total hydraulic loading on the wastewater treatment system utilized by given plants. This aspect and others associated with minimizing the use of water in this operation are discussed in Section 4 of this report.

3.3 Commodity Specific Process Descriptions

Specific process descriptions are included for the following commodities:

- Apples and apple sauce
- Peaches, pears and apricots
- Cherries and plums
- Berries
- Corn
- Peas and beans (blanched vegetables)
- Beets and carrots

Tomatoes

Sauerkraut

Pickles and relishes

Jams and jellies.

It is considered that the above list of commodities reflects the major fruits and vegetables processed in Canada based on a review of Canadian statistics given in Section 7. It should be pointed out that this list is not exhaustive with respect to the total processing industry in Canada, nor does it include all the specific commodities discussed in recent publications by the United States Environmental Protection Agency [2] [3].

Each commodity is discussed in the order given above, and includes a general description of the processing operations which are major sources of pollutants and a discussion of wastewater characteristics. The data presented within this section are taken principally from United States publications and information made available by Environmental Associates, Inc. for this study. These data are used to develop the framework within which the Canadian fruit and vegetable industry is assessed.

3.3.1 Apples and apple sauce

Apple processing includes storage, washing and sorting, peeling and coring, slicing, chopping, juice extraction, dehydration, deaeration and cooling. Final products are apple sauce, juice, and frozen and canned apple slices. A schematic flow sheet of these processes is shown in Figure 1.

Apples received from the field or storage are washed to remove all residues remaining on the fruit; chemicals or detergents are added as required to assist in the removal of residues. Water reuse is practised at this point to conserve water and reduce the volume of effluent as indicated on the flow sheet in Figure 1. Smaller and malformed apples are removed at this point in the process and directed to the juice operation.

Mechanical peeling is generally used to remove the skin, and the peel and core are sometimes collected for the use in the production of juice or vinegar stock. This solid fraction represents approximately 35% of the total weight of apple processed. Steam and caustic peeling are also used, generally in the manufacture of sauce. Final removal of the peel is accomplished using water spray or abrasive scrubbers.

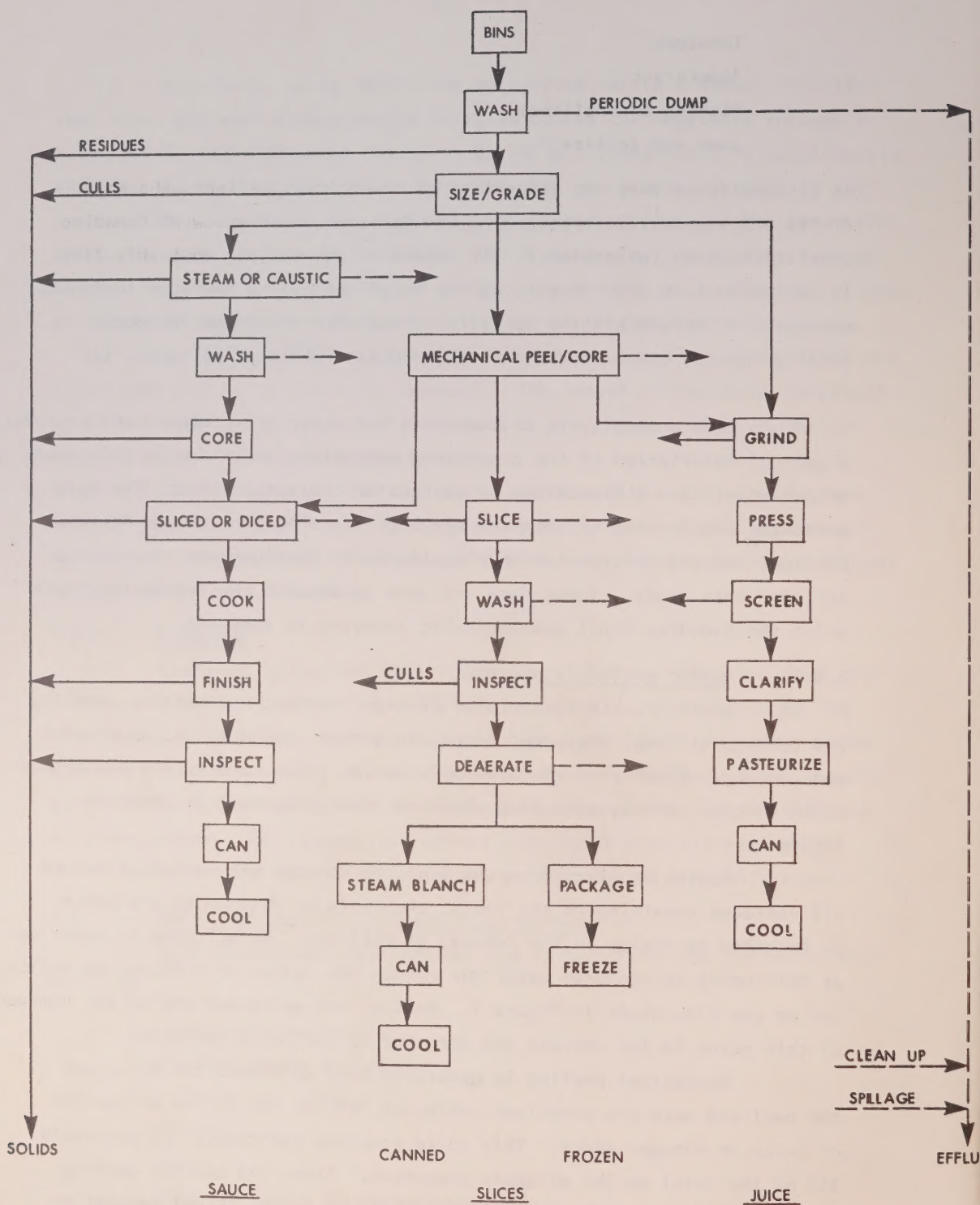


FIGURE 1. PROCESSING SCHEMATIC FLOW SHEET - APPLES

After the core is removed, the apples are cut for the production of apple slices. These are washed, graded, and inspected prior to further processing into dehydrated, frozen or canned products. The slices are de-aerated by immersion in brine before the freezing or canning processing steps. In the canning operation, the slices are steam blanched or preheated, canned while hot and further cooked to ensure preservation.

Apple sauce is prepared from comminuted or chopped apples. Water and sugar are added, and the cored apples sliced or diced in small pieces, cooked and passed through a finisher to remove large particles. The hot apple sauce is inspected and canned.

Apple juice is an unfermented liquid prepared from fresh whole sound apples or apple pieces such as cores or peelings obtained from either a slice or sauce processing line. Whole apples are washed and comminuted prior to pressing and juice screened to remove large particles and possibly clarified by diatomaceous earth pressure filtration. The juice is sealed in containers and heated.

Vinegar stock is prepared in a manner similar to that for apple juice except that the raw material is poor quality apples. It is not clarified to the same degree as apple juice and is usually concentrated prior to bulk shipment to a vinegar processing plant.

3.3.2 Peaches, pears and apricots

Peaches, pears and apricots are grouped together because of similarity of in-plant processes, wastewater characteristics and wastewater treatability.

3.3.2.1 Peaches. There are two main varieties of peaches, clingstone and freestone. These fruits are harvested by hand: clingstone when ripe, and freestone several days before tree ripening. A schematic flow sheet of the process is shown in Figure 2.

The peaches are dumped into a recirculating wash water tank after arrival at the food processing plant. After this initial wash to remove debris and soil residues, the peaches are sprayed under high pressure to remove final residues. The peaches are transported by flumes to size graders and distributed to the various processing lines. Sorting and grading operations occur before and after picking and subsequent to the lye peeling operation.

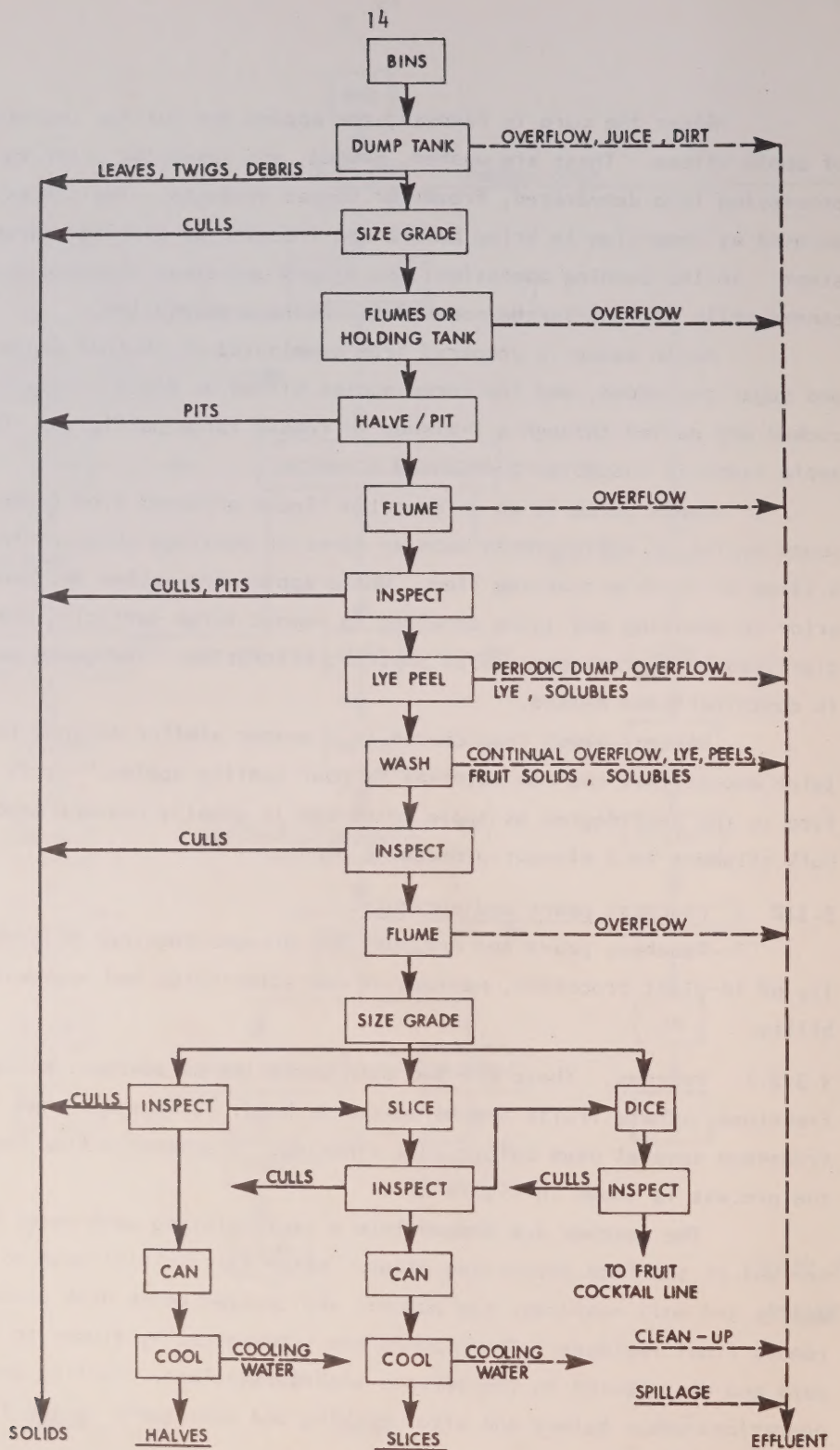


FIGURE 2. PROCESSING SCHEMATIC FLOW SHEET - PEACHES

The peaches are pitted and, after inspection, are peeled using hot lye solution, generally followed by high pressure water sprays. This peel may also be removed by rubber disks and the waste removed by a dry conveyor. After washing and inspection, the peaches are graded for the production of halves or slices, or for the preparation of fruit cocktail.

3.3.2.2. Pears. Pears do not ripen successfully on the tree and are therefore picked green; they are harvested by hand and ripened in controlled atmospheric conditions. A schematic flow sheet of the in-plant process is shown in Figure 3.

The pears are dumped into a recirculating wash water tank to remove debris and soil and to cool the fruit. They are then graded and placed in either cold storage or in a controlled atmosphere until the desired ripeness is attained, sometimes for a period of several weeks.

After further ripening, as required, the pears are rewashed and peeled by either a mechanical operation or by immersion in hot lye solution followed by a water spray wash. The peeling operation is followed by mechanical coring and halving. After inspection and cleaning, as required, the pears are graded for production of halves, slices or nectar.

Pears with blemishes or smaller fruit of insufficient quality to be canned as halves are sent to the slicing line. After passing through a mechanical slicer, unsuitable material is routed through to the dicing machine and the nectar line. After can filling and topping with syrup, the halves and slices are passed through continuous cookers and cooled with water sprays. The dices are combined with peach dices, pineapple, grapes and cherries to be canned as fruit cocktail.

3.3.2.3. Apricots. Apricots are tree ripened and harvested by hand, only mature fruit being selected. After dumping into a tank for preliminary washing and removal of debris, the apricots are manually sorted, mechanically sized and graded and then distributed to one of four lines: whole, half, nectar or concentrate processing lines. (Figure 4)

Apricots are normally peeled prior to canning but some operations process unpeeled whole fruit. After lye peeling, the apricots are spray washed and screened. The whole fruit is inspected, with overripe and green fruit being diverted to nectar or concentrate operations. The quality "cots" are canned. Apricots canned as halves are not peeled but are cut, inspected and washed prior to the canning operation.

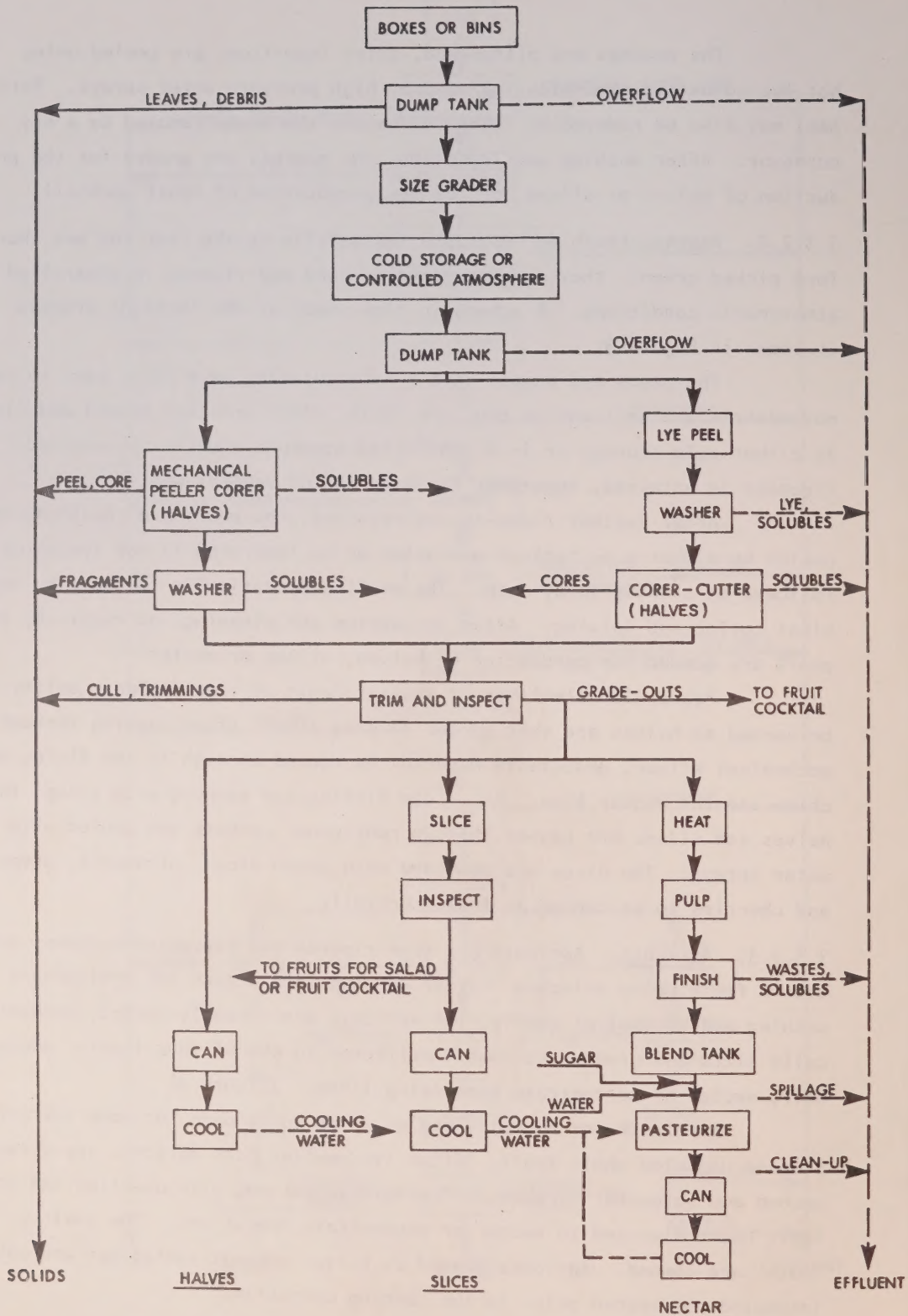


FIGURE 3. PROCESSING SCHEMATIC FLOW SHEET - PEARS

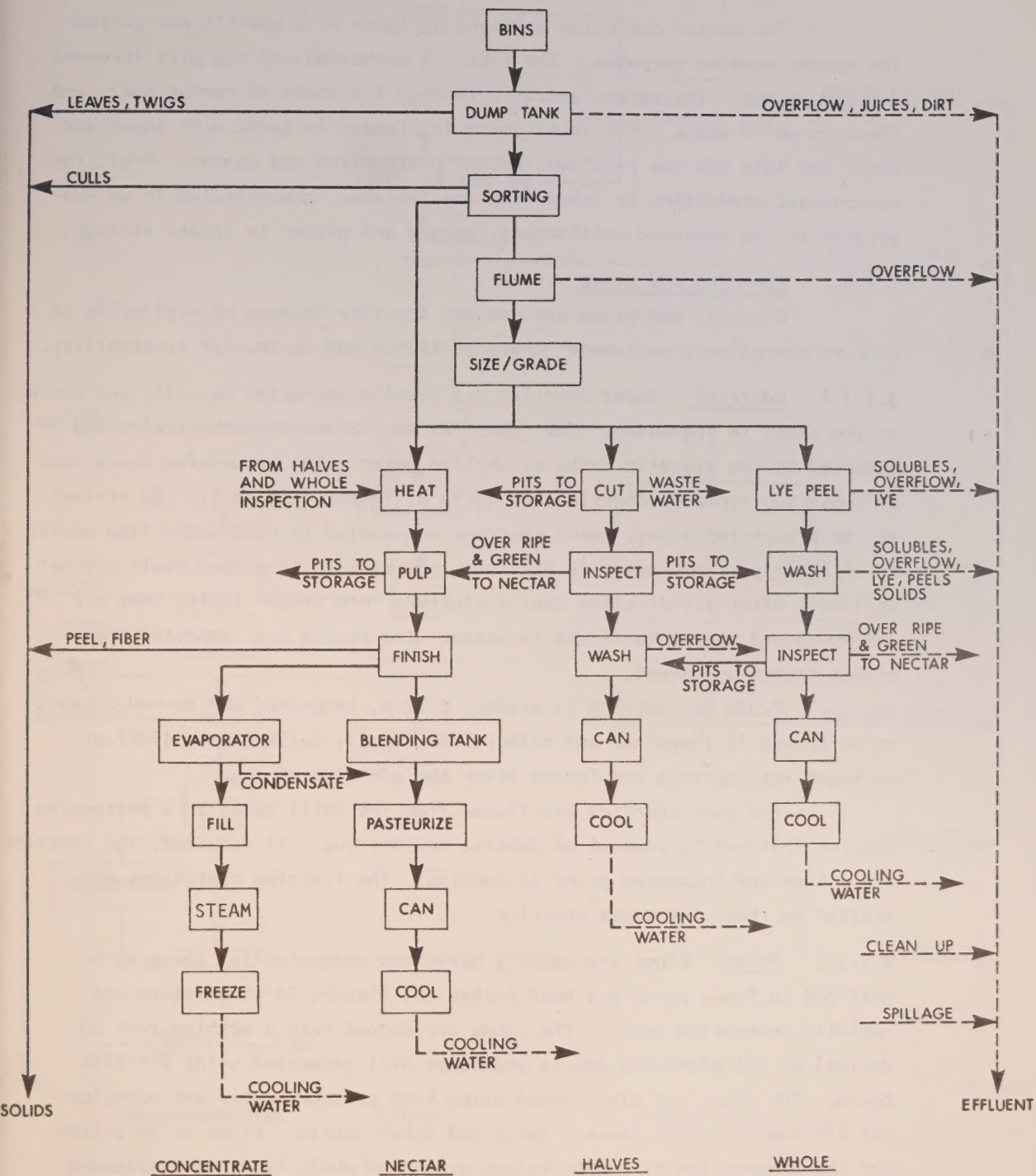


FIGURE 4. PROCESSING SCHEMATIC FLOW SHEET - APRICOTS

The nectar operation utilizes apricots of a quality not suited for normal canning purposes. The fruit is preheated and the pits screened out and washed. The puree is passed through finishers to remove peels and fibre as solid waste. The fruit juice is blended in tanks with sugar and water and pulp and the resultant nectar pasteurized and canned. Fruit for concentrate production is taken from the finisher, concentrated in an evaporator to the required consistency, canned and placed in frozen storage.

3.3.3. Cherries and plums

Cherries and plums are grouped together because of similarity of process operations, wastewater characteristics and wastewater treatability.

3.3.3.1 Cherries. Sweet cherries are usually harvested manually and hauled to the plant in lug boxes. Tart cherries are harvested mechanically and conveyed to the plant in tanks of chilled water. The processing operations of these two types of cherries are quite different (Figure 5). On arrival at the processing plant, sweet cherries are cooled in continuous flow coolers or in chilling rooms prior to pitting; cherries to be packed whole are not chilled. After dividing the cherry clusters into single fruit, they are destemmed and the stems flumed to waste. The fruits are inspected and either frozen or canned.

Fruit for canning is graded, pitted, inspected and canned. Fruit to be frozen is inspected and either individually quick frozen (IQF) or packaged into cartons and frozen after the addition of sugar.

The sour cherries are flumed from the chill tanks to a destemming machine followed by removal of debris, and sorting. If required, the cherries are pitted and inspected prior to canning. The freezing operations are similar to those for sweet cherries.

3.3.3.2 Plums. Plums are usually harvested mechanically; those to be utilized in fancy packs are hand picked and ripened in temperature and humidity controlled rooms. The plums are dumped into a washing tank on arrival at the plant and debris and loose dirt separated using a riffle board. The plums are also rinsed using high pressure water and sometimes air cleaned to remove leaves, twigs and other debris. Plums to be pitted for the preparation of canned halves or canned whole fruit are destemmed prior to either final size grading or halving. (Figure 6)

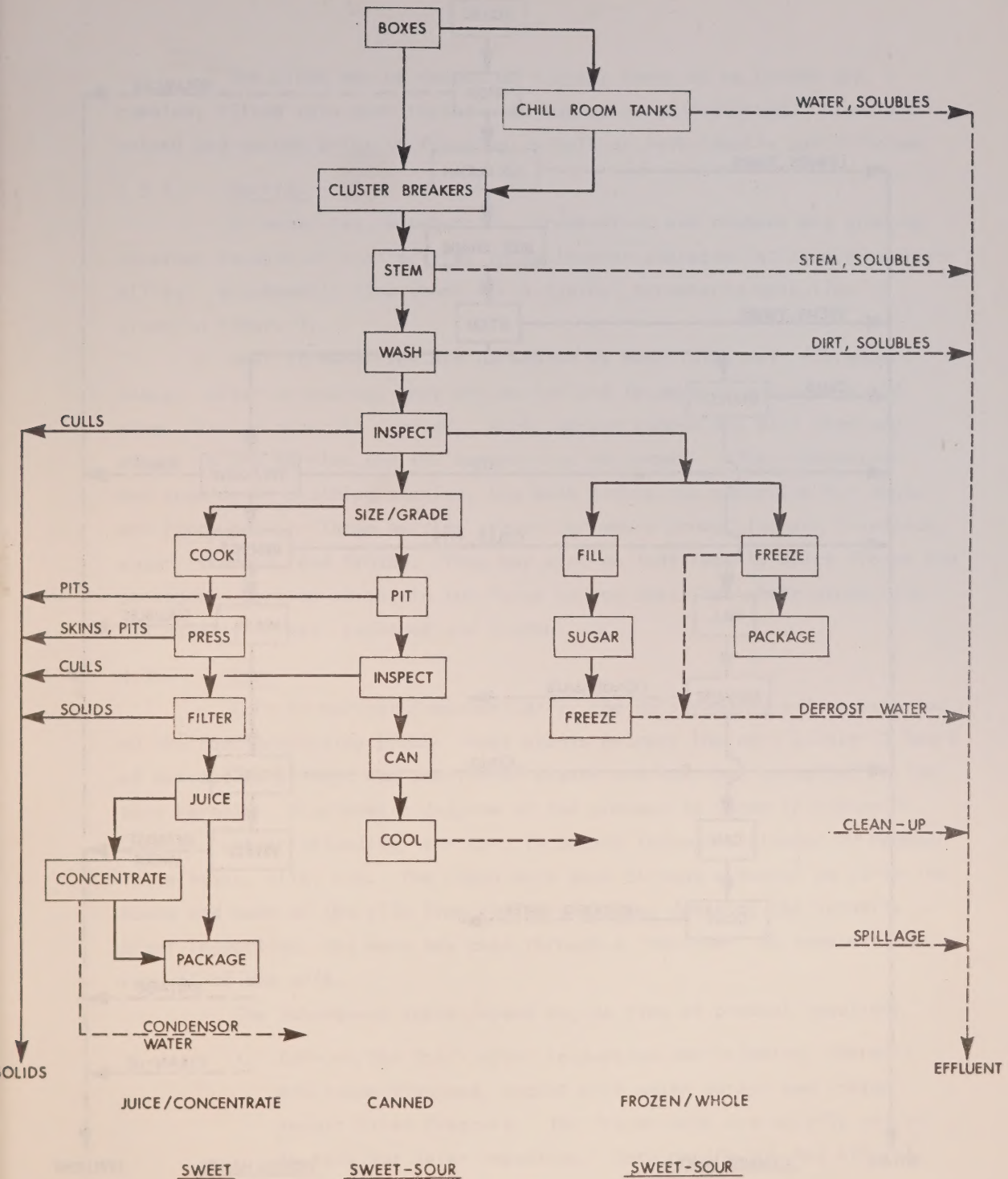


FIGURE 5. PROCESSING SCHEMATIC FLOW SHEET - CHERRIES

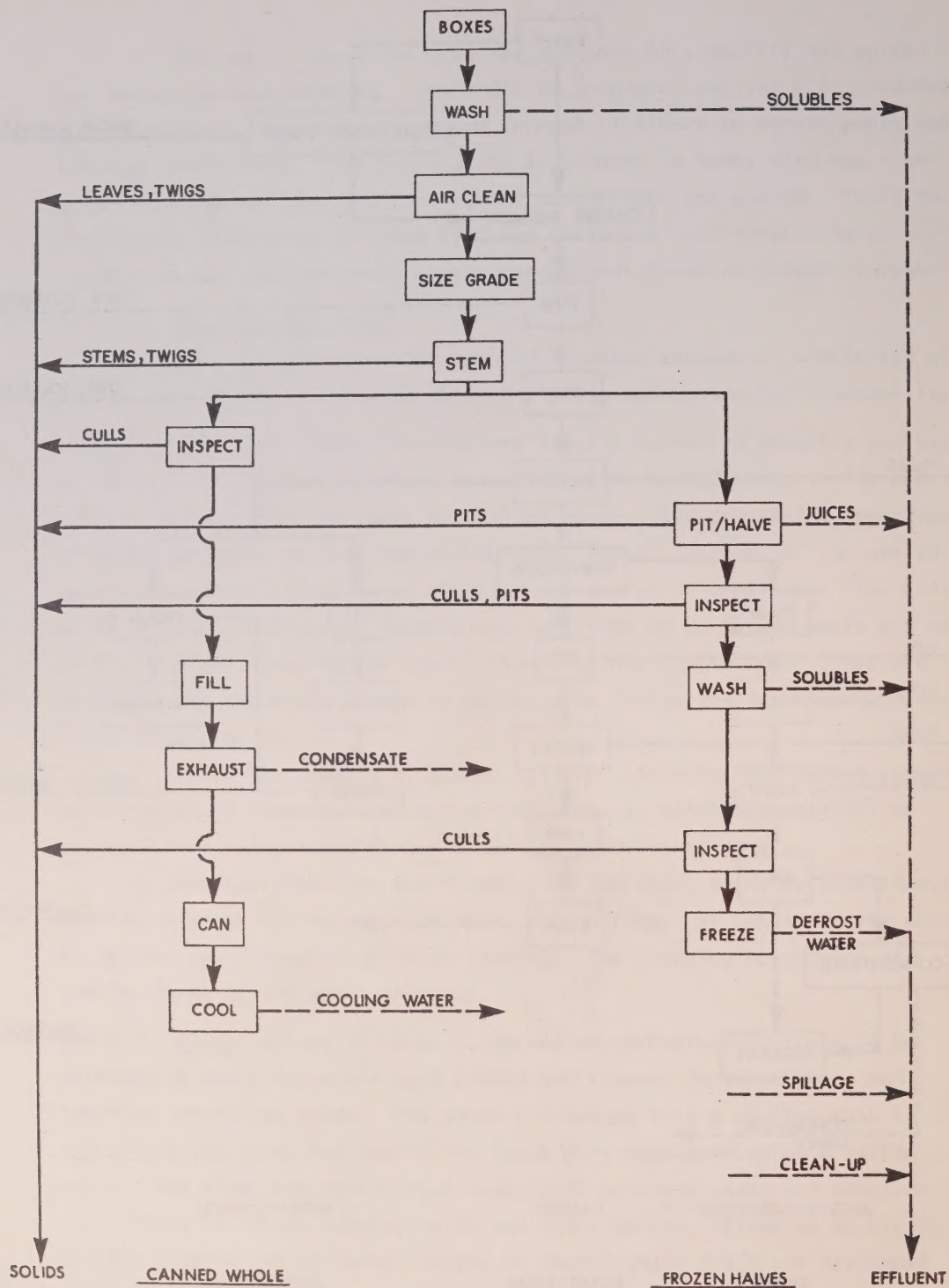


FIGURE 6. PROCESSING SCHEMATIC FLOW SHEET - PLUMS

The plums may be canned or frozen; those to be canned are tumbled, filled into cans topped with hot syrup and retorted. Plums are halved and washed prior to freezing in bulk or individually quick frozen.

3.3.4 Berries

Strawberries, blueberries, cranberries and rhubarb are grouped together because of similarities in wastewater characteristics and treatability. A schematic flow sheet for a typical strawberry operation is given in Figure 7.

Most strawberries are harvested by hand into small fibreboard boxes. After unloading, they are washed and inspected, and debris and other foreign material removed. Water sprays remove any dirt that may adhere to the berries and the berries are destemmed. After inspection and grading in a sizing machine, the best fruits are separated for whole and fancy packs. Those berries graded for whole production are inspected, sugar is added, and frozen. They may also be individually quick frozen and packaged. Berries which are too large or too small for whole production are usually pureed, packaged and frozen.

3.3.5 Corn

Corn is harvested mechanically, the ears removed and transported to the food processing plant. Most plants process the corn within 12 hours of harvest to prevent degradation of sugars and starches contained in the corn kernels. A schematic diagram of the process is shown in Figure 8.

After unloading, the corn is passed through a cleaner to remove loose husks, silk, etc. The clean ears pass through a husker to strip the husks and much of the silk from the ears without damaging the kernels. After inspection, the ears may pass through a "desilker" to complete the removal of the silk.

The subsequent steps depend on the type of product required:

1. Corn on the Cob - After inspection and trimming, the ears are steam blanched, cooled with water sprays and frozen in air blast freezers. The frozen cobs are usually stored in bulk for later repacking. Corn on the cob may also be canned.

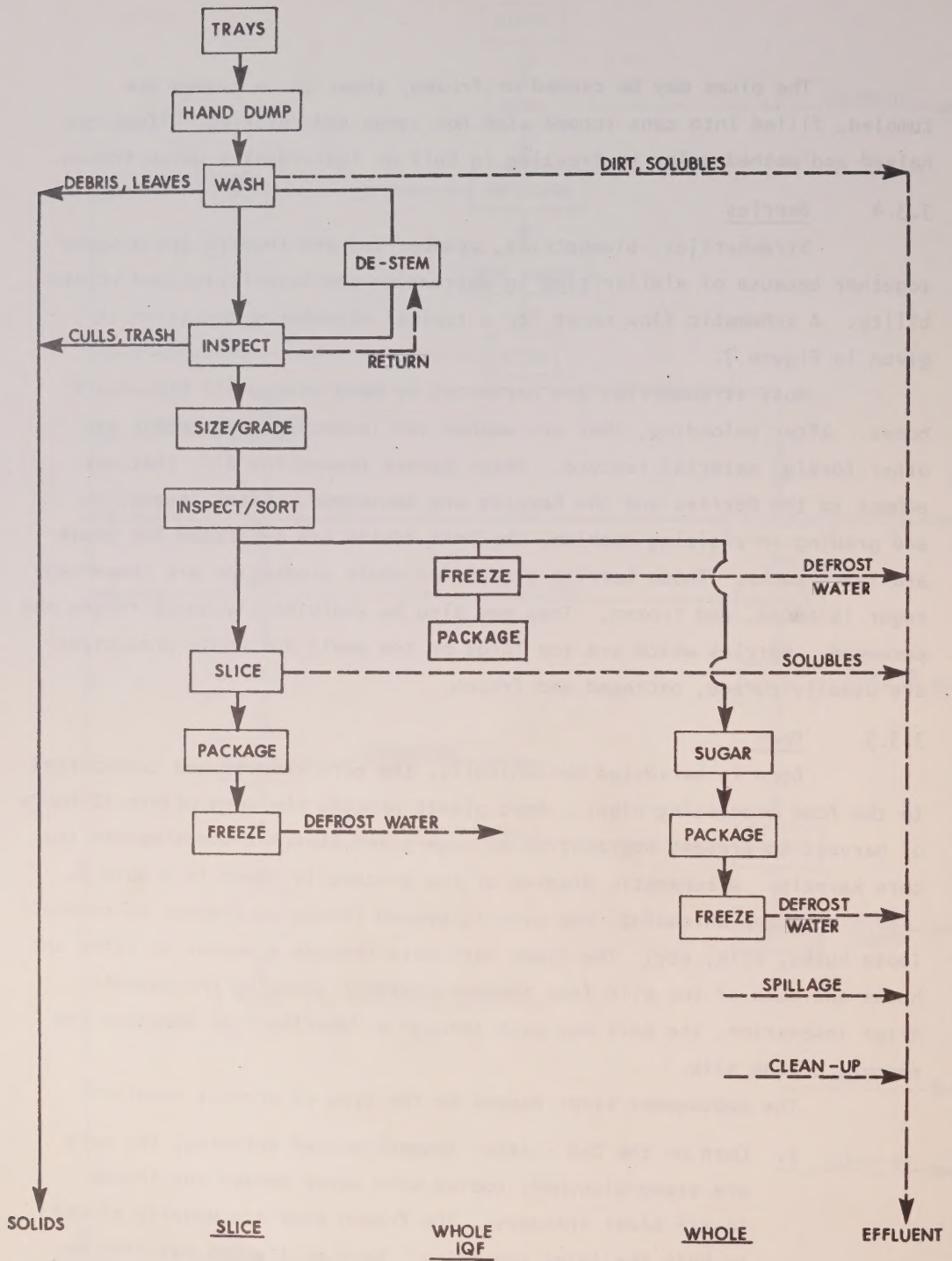
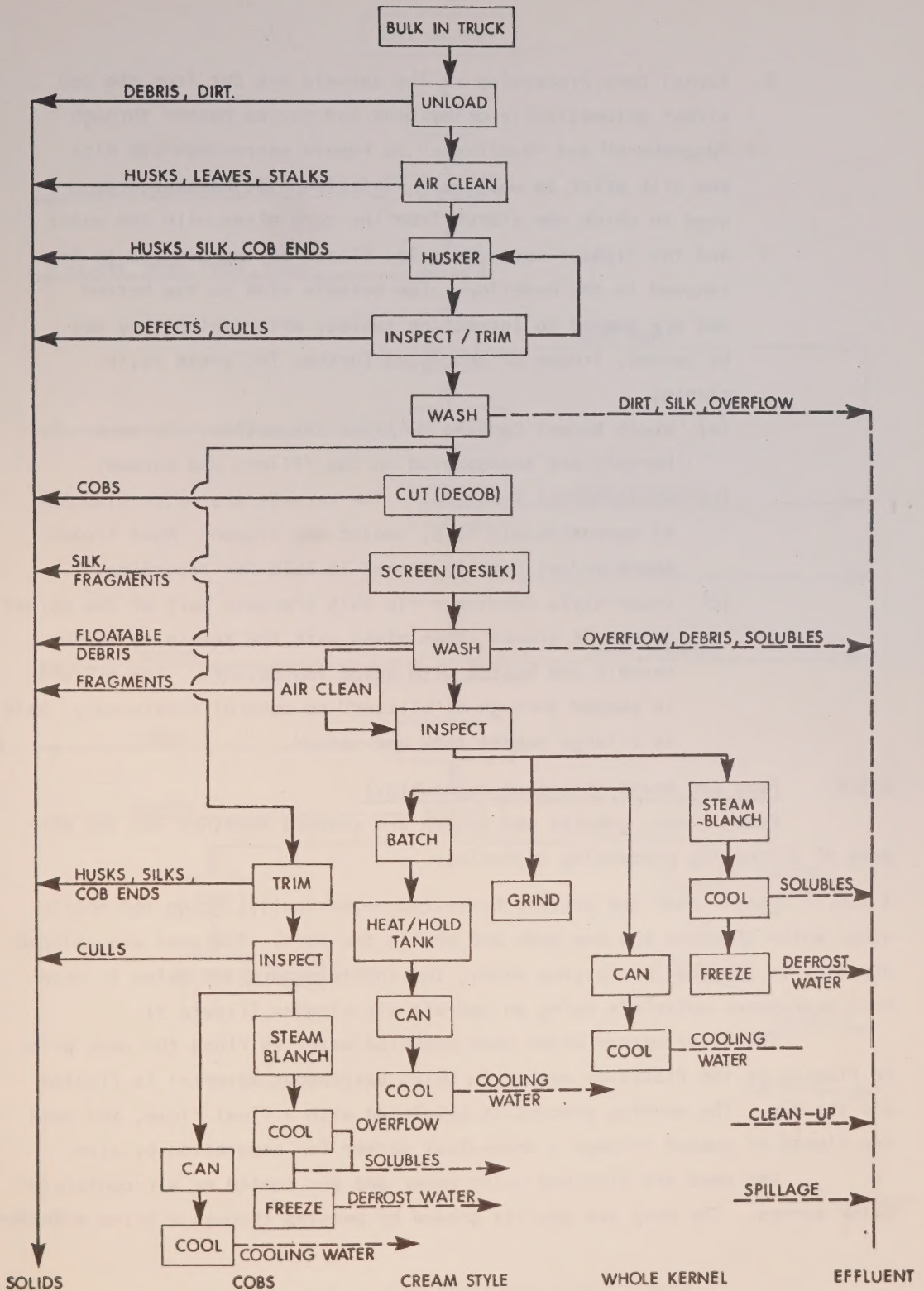


FIGURE 7. PROCESSING SCHEMATIC FLOW SHEET - STRAWBERRIES



2. Kernel Corn Processing - The kernels are cut from the cob either automatically or by hand and may be passed through "decobbers" and "desilkers" to remove extraneous cob bits and silk prior to washing. Flotation-type washers are used in which the starch from the corn mixes with the water and the lighter waste material floats to the surface to be removed in the overflow. The kernels sink to the bottom and are pumped to inspection tables, after which they may be canned, frozen or processed further for cream style canning.
 - (a) Whole Kernel Canning - After inspection, the corn kernels are transported to the fillers and canned.
 - (b) Whole Kernel Freezing - The kernels are water blanched at approximately 80°C, cooled and frozen. Most frozen whole kernel corn is stored in bulk for repacking.
 - (c) Cream Style Canning - In this process, part of the kernel stream is ground, then mixed with the remaining whole kernels and heated with added ingredients. The mixture is pumped through a "slitter" to control consistency, held in a large heated tank and canned.

3.3.6 Peas and beans (blanched vegetables)

Peas, beans, pumpkin and squash are grouped together for the purpose of discussing processing technology.

3.3.6.1 Peas. Peas are usually harvested mechanically, using the mobile viner which threshes the pea pods and shells the peas. The peas are shipped directly to the food processing plant, the initial operation being to separate extraneous materials using an updraft air cleaner (Figure 9).

The first washer often uses recycled water to rinse the peas prior to fluming to the flotation washer in which extraneous material is floated off the top. The washing process is completed with a final rinse, and peas are flumed or pumped through a mechanical sorter for separation by size.

The peas are blanched using water and are cooled by air coolers or water sprays. The peas are quality graded by passing through a brine solution

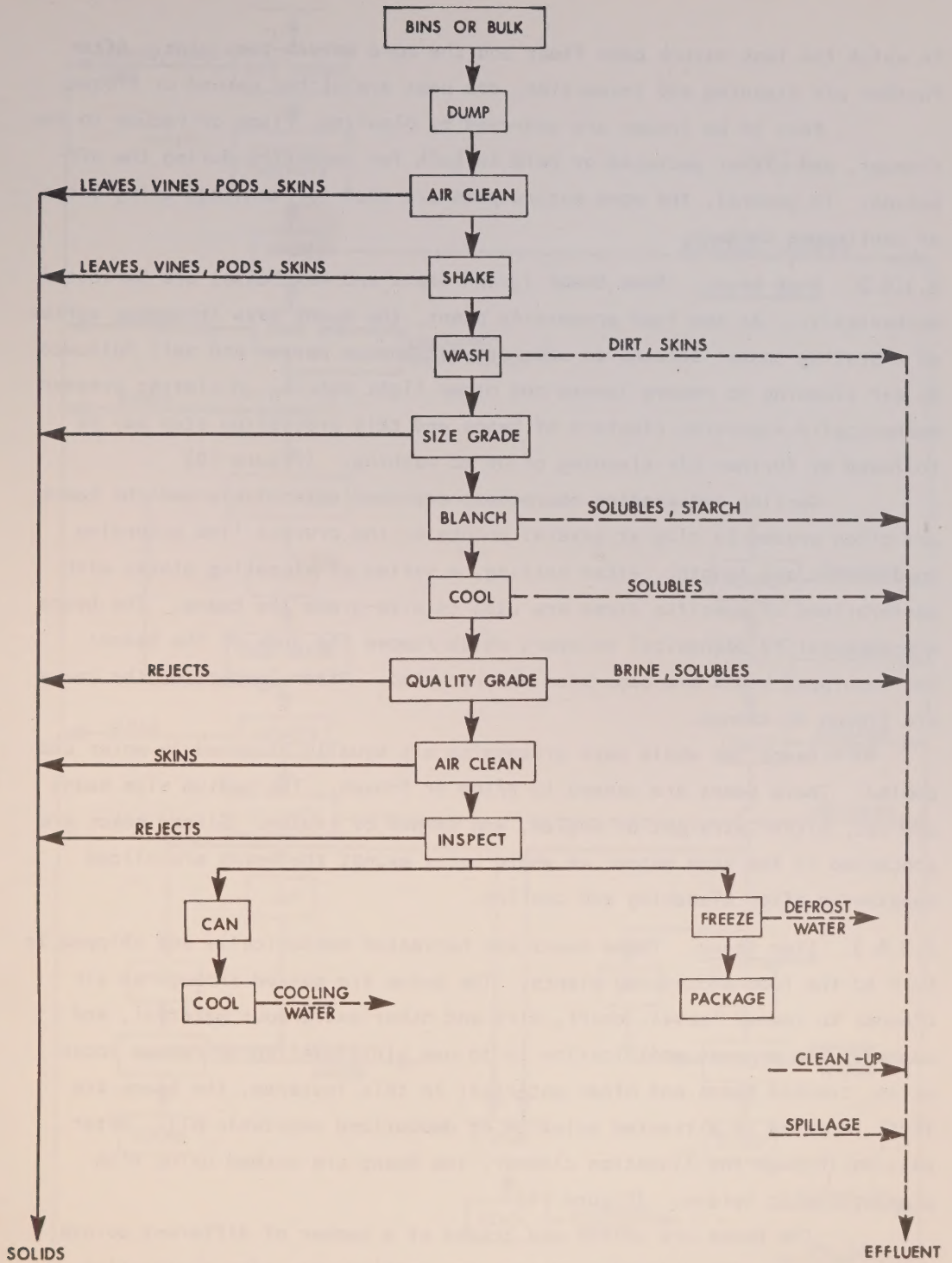


FIGURE 9. PROCESSING SCHEMATIC FLOW SHEET - PEAS

in which the less mature peas float and the more mature peas sink. After further air cleaning and inspection, the peas are either canned or frozen.

Peas to be frozen are conveyed by pipeline, flume or vacuum to the freezer, and either packaged or held in bulk for repacking during the off-season. In general, the more mature peas are used for canning, using batch or continuous cookers.

3.3.6.2 Snap beans. Snap beans (green beans and wax beans) are harvested mechanically. At the food processing plant, the beans pass through a series of vibrating shaker screens to separate extraneous matter and soil followed by air cleaning to remove leaves and other light debris. A cluster breaker mechanically separates clusters of beans and this processing step may be followed by further air cleaning prior to washing. (Figure 10)

Sorting and grading operations are used extensively and the beans are often graded by size at several points on the process line according to diameter and length. After cutting, a series of vibrating plates with perforations of specific sizes are used to size-grade the beans. The beans are then cut by mechanical snippers which remove the ends of the beans; the unsnipped beans are separated and recycled. After inspection the beans are frozen or canned.

Beans for whole pack processing are usually blanched in water and cooled. These beans are canned in brine or frozen. The medium size beans are cut, either straight or angled, and canned or frozen. Sliced beans are processed in the same manner as whole beans except the beans are sliced lengthwise after blanching and cooling.

3.3.6.3. Lima beans. These beans are harvested mechanically and shipped in bulk to the food processing plants. The beans are passed through an air cleaner to remove leaves, chaff, dirt and other extraneous material, and washed. One process modification is to use air flotation to remove loose skins, cracked beans and other material; in this instance, the beans are first immersed in a treated solution of deodorized vegetable oil. After passing through the flotation cleaner, the beans are washed using high pressure water sprays. (Figure 11)

The beans are sorted and graded at a number of different points in the process, the initial grading being carried out using a vibrating mechanical shaker. After manual inspection, the beans are blanched and rapidly cooled to approximately 21°C to preserve color and maintain quality.

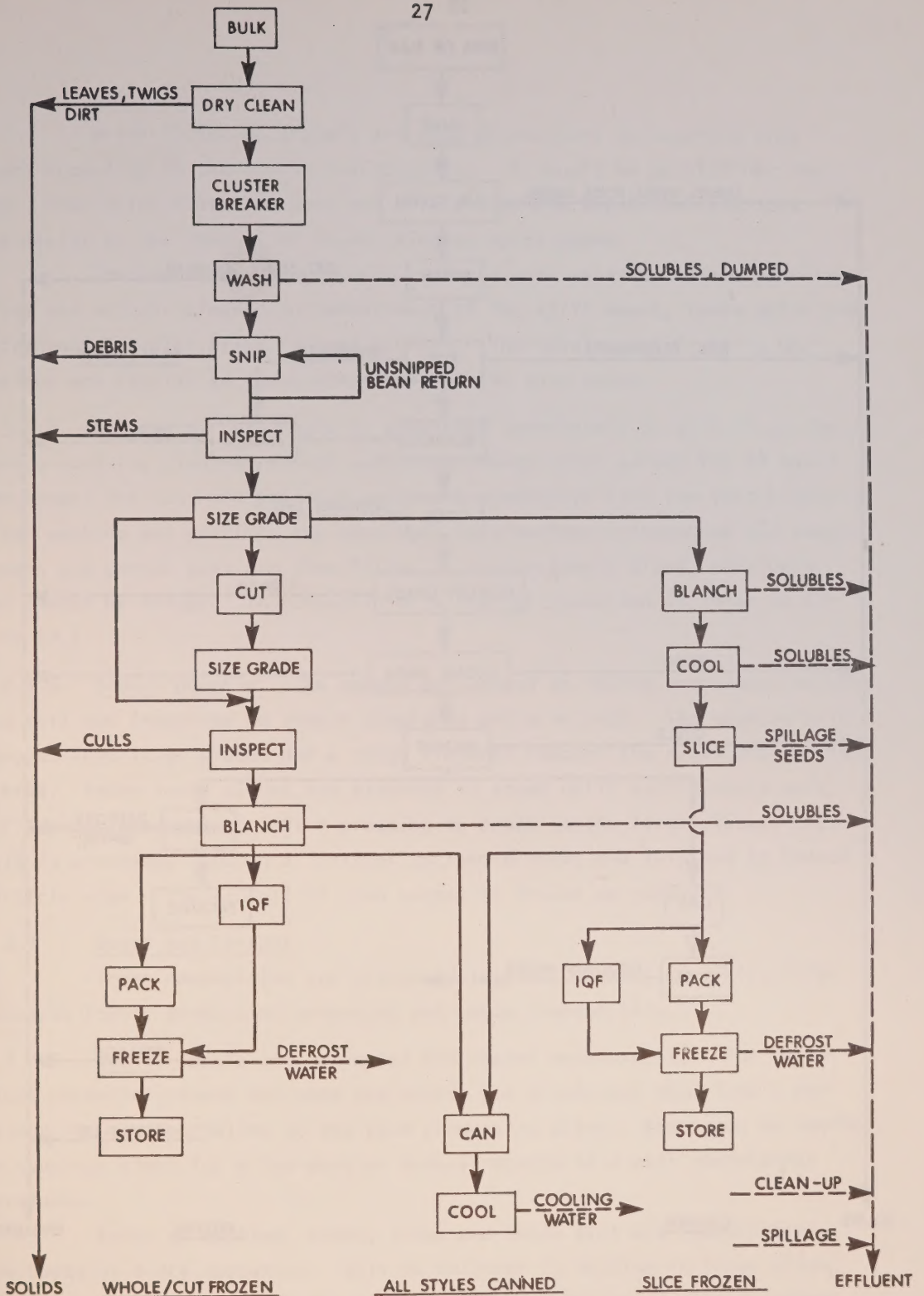


FIGURE 10. PROCESSING SCHEMATIC FLOW SHEET - SNAP BEANS

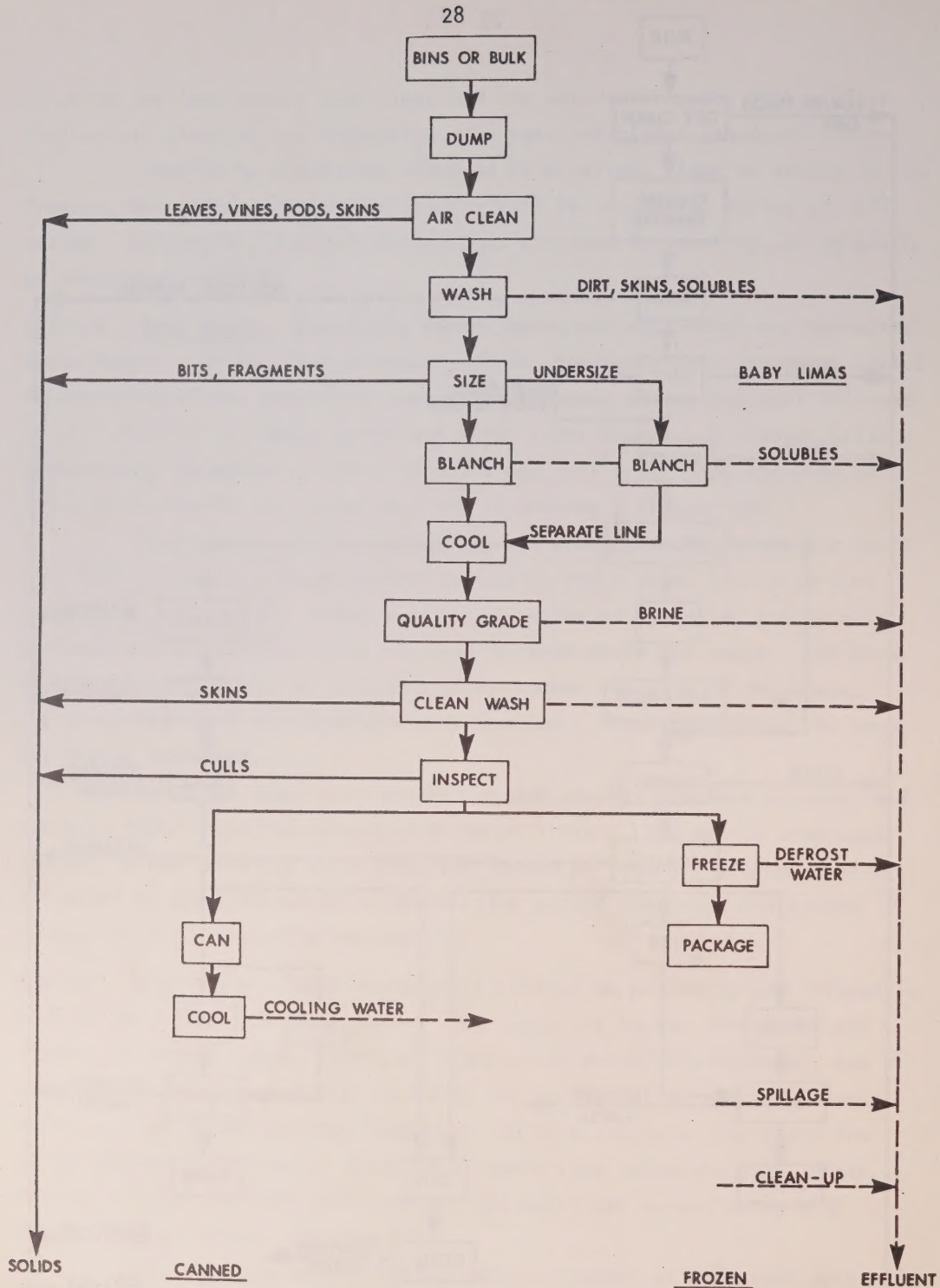


FIGURE 11. PROCESSING SCHEMATIC FLOW SHEET - LIMA BEANS

Brine flotation graders are used extensively to separate lima beans according to tenderness and maturity. It should be pointed out however, that brine flotation does not give a complete separation and does not assist in the removal of loose skins or split beans.

The beans are sprayed with high pressure water to remove adhering brine and are air cleaned to remove most of the split beans, loose skins and extraneous material prior to hand picking. The canning and freezing operations are similar to those described for the snap beans.

3.3.6.4. Asparagus. Asparagus is processed immediately on arrival at the food processing plant or stored under continuous water sprays for 24 hours. The spears are cut, and the tips processed separately from the centre cuts. After washing and grading, the asparagus is blanched, reinspected and recut. Spears and center cuts are then filled in appropriately sized containers and canned or frozen. (A schematic of a typical operation is shown in Figure 12.)

3.3.6.5 Squash-pumpkin. The squash are washed to remove extraneous matter and soil and inspected to remove blemishes and stem ends. The vegetable is chopped into large pieces and a rough finisher removes the seeds and coarse fibres. These large pieces are blanched in steam until sufficiently soft for further processing. After pressing to break up the large pieces, the bulk is processed through a finisher to remove seeds and skin and to reduce particle size. The product is then canned or frozen as required.

3.3.7 Beets and Carrots

These commodities are discussed together because of similarities in waste loads, production processes and waste treatability.

3.3.7.1 Beets. Beets are harvested and topped mechanically. The mechanical harvester cleans and tops the beets, and discharges them into a container for transportation to the food processing plant. Beets can be stored on concrete slabs for a few days or several months in a well ventilated warehouse.

Prior to washing, stems, trash and loose dirt are removed from the beets by a dry operation; this is followed by washing in large brush washers or rotating wheel washers to remove the majority of silt or leaves

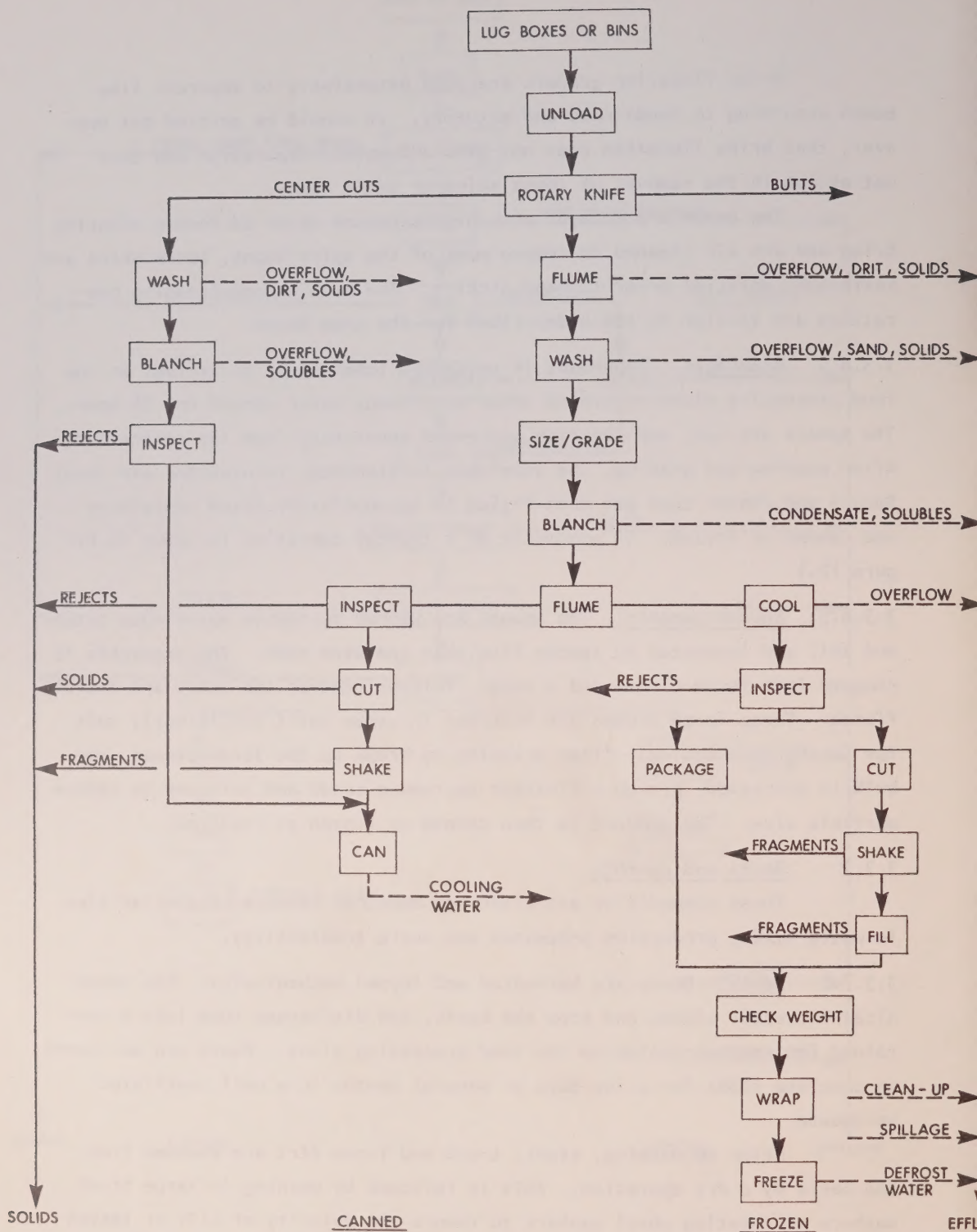


FIGURE 12. PROCESSING SCHEMATIC FLOW SHEET - ASPARAGUS

from the beets. Beets are size graded at a number of points in the process to segregate the vegetables for peel removal and for product style. (Figure 13)

The product is preheated using water baths or atmospheric steamers. This step is followed by either high pressure steaming or the addition of hot caustic soda. Peel removal may be accomplished by high pressure water sprays or by abrasive peelers. After manual trimming and inspection, and hand removal of soft beets, the vegetables are graded according to size and transported to the appropriate processing line.

Small, almost spherical beets are canned whole. Medium size beets are sliced and canned, and the large and irregularly shaped beets are diced, "shoestringed" or sectioned. Small beets are washed and filled in a tumble type filler, the containers topped with hot brine and cooked and cooled. Cooking is carried out in batch or in continuous cookers.

3.3.7.2 Carrots. The processing operation for carrots is similar to that described for beets. The carrots are stored on a concrete slab prior to washing; subsequent to the wash step, the carrots are peeled, using either abrasive or lye techniques, and inspected before slicing or dicing. (Figure 14)

In the production of carrot juice, the vegetables are first pulped and pressed to remove the juice which passes through a finisher to remove the larger pieces prior to deaeration and subsequent canning. In the canning of sliced or diced carrots, they are placed in the can and cooked in a retort. Carrots to be frozen are blanched prior to packaging and freezing.

3.3.8 Tomatoes

Tomatoes are generally harvested mechanically and transported in wooden bins or gondolas to the food processing plant. Mechanical harvesting, in contrast to hand picking, increases the quantities of soil and organic solids included with the raw product and results in a greater percentage of damaged tomatoes being delivered. A schematic of the processing operation is shown in Figure 15.

The initial wash removes most of the remaining extraneous material and soil, and this is followed by high pressure rinses to remove final residues. Tomatoes are generally transported by the water flumes from the washers through size graders for separation in use of whole pack, juice or

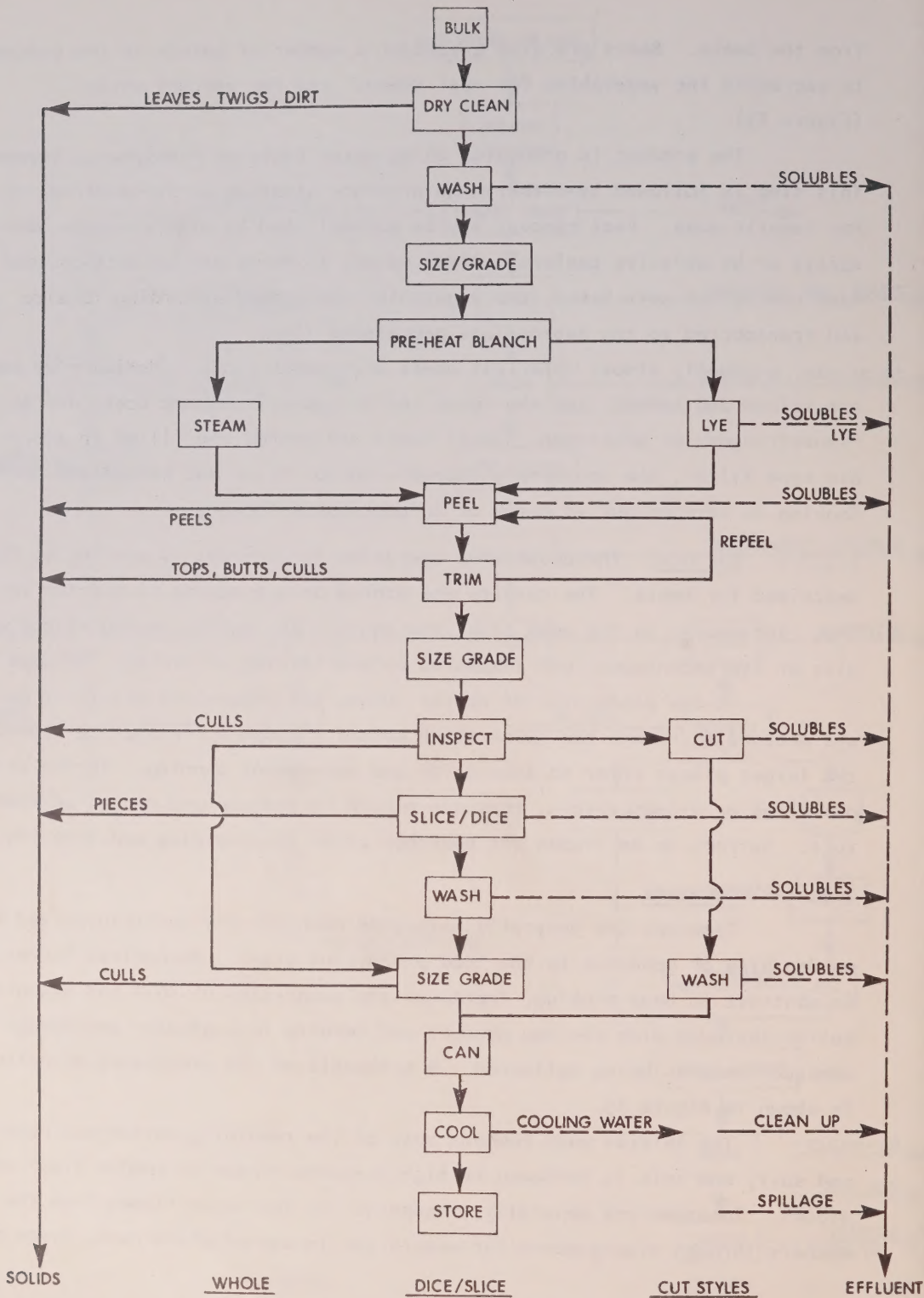


FIGURE 13. PROCESSING SCHEMATIC FLOW SHEET - BEETS

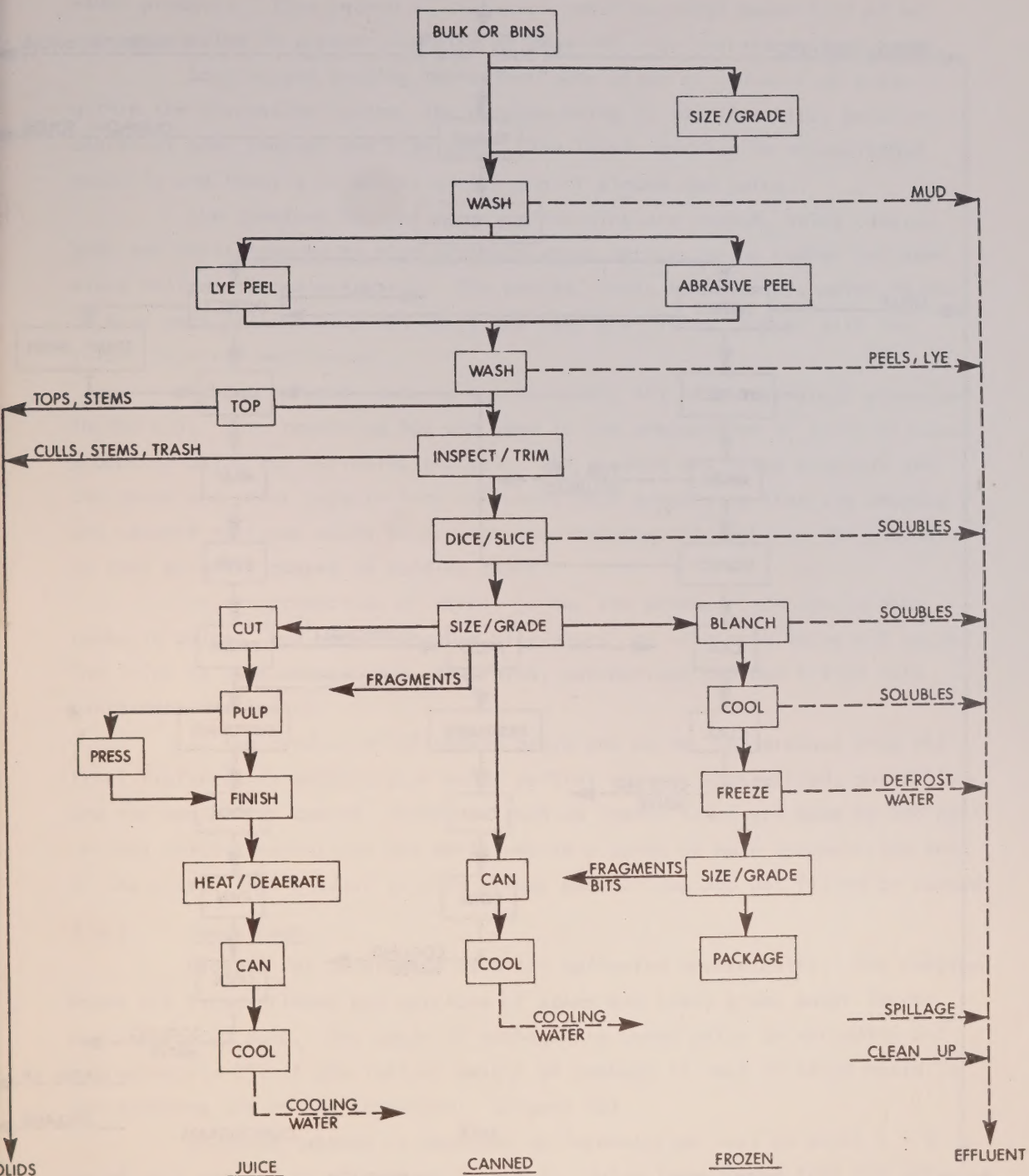


FIGURE 14. PROCESSING SCHEMATIC FLOW SHEET - CARROTS

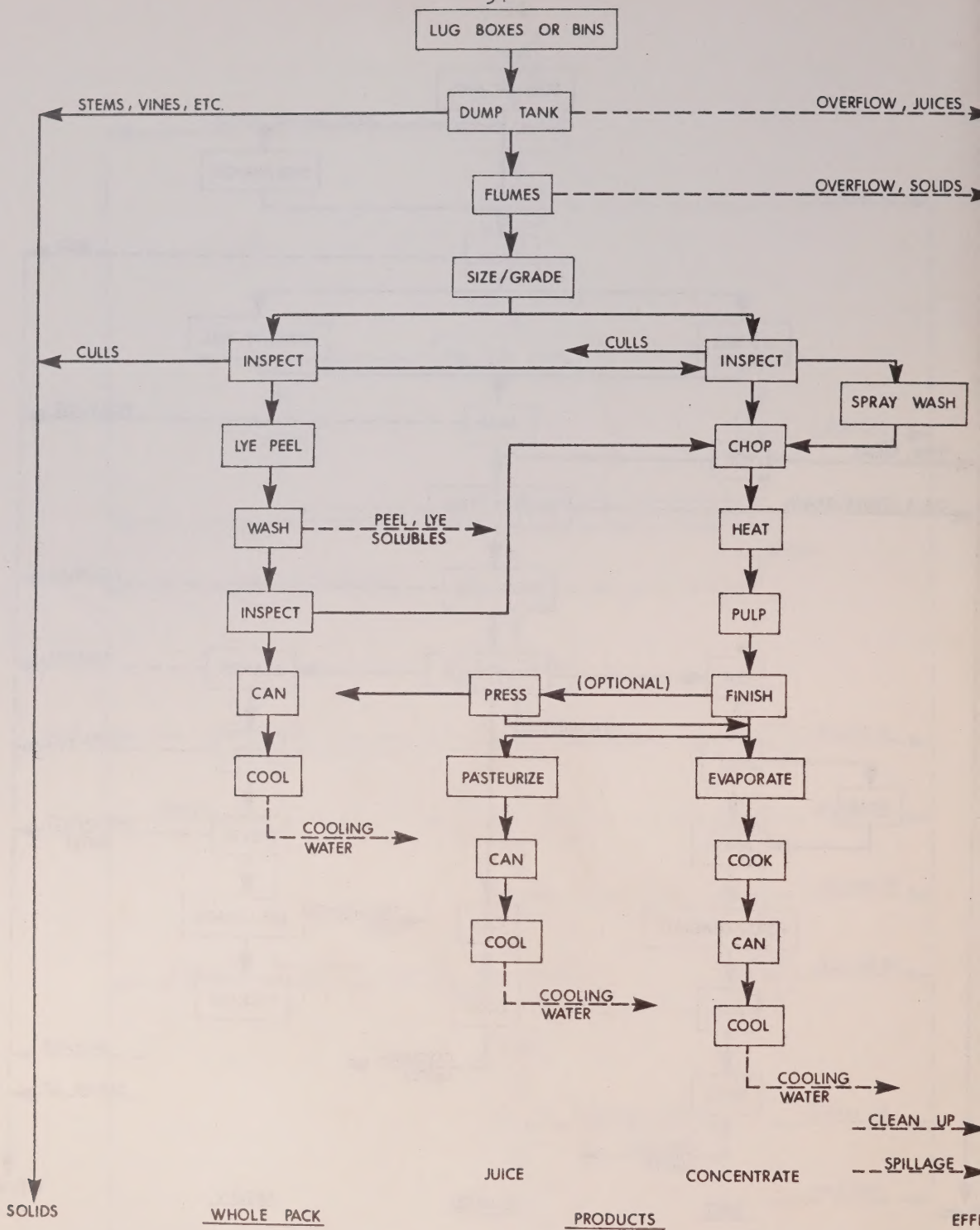


FIGURE 15. PROCESSING SCHEMATIC FLOW SHEET - TOMATOES

sauce products. This method of transport requires large quantities of water and results in greater leaching of organics into the wastewater stream.

Sorting and grading operations take place at a number of points within the processing system, the purpose being to sort for size, maturity, degree of peel removal and blemishes. The latter sorting is accomplished manually and results in wastes consisting of pieces and juice.

The tomatoes for whole pack processing are peeled, using caustic soda and peels removed by high pressure water sprays, or by rubber scrubber disks followed by water sprays. The peeled, whole tomatoes are water flumed to hand pack filling machines where the cans are filled, topped with hot juice, retorted and cooled.

Canned tomatoes make up approximately 10% of the tomatoes processed in the U.S. The remaining 90% are used in the preparation of juice or sauce products, using the following process: the cleaned and sized tomatoes and the shape and color rejects from the whole pack processing line are chopped and exposed to steam coils to prevent the breakdown of pectins; the product is then normally pumped to holding tanks.

In the production of tomato juice, the product from the holding tanks is pulped and passed through "finishers" to eliminate skins and seeds. The juice is then homogenized, deaerated, pasteurized and hot filled into containers and cooled.

In the production of tomato paste and puree, the product from the final finishers is concentrated under partial vacuum, pasteurized, hot filled and the containers cooled. Products such as tomato sauce are made by adding various spice formulations and additives to a puree or more concentrated form as the base. This product is then either pasteurized and hot filled or canned.

3.3.9 Sauerkraut

Cabbage for sauerkraut is often harvested mechanically. The cabbage heads are first trimmed and portions of stems and heavy green outer leaves are removed by hand. The heads of cabbage are cored prior to shredding and approximately 25% of the initial weight of cabbage is lost to solid waste in the trimming and coring operation. (Figure 16)

Shredded cabbage is conveyed to fermentation vats to which 2 - 3 kg of salt per 100 kg of cabbage is added. Juice is released from the cabbage almost immediately after the addition of salt and, to ensure maximum

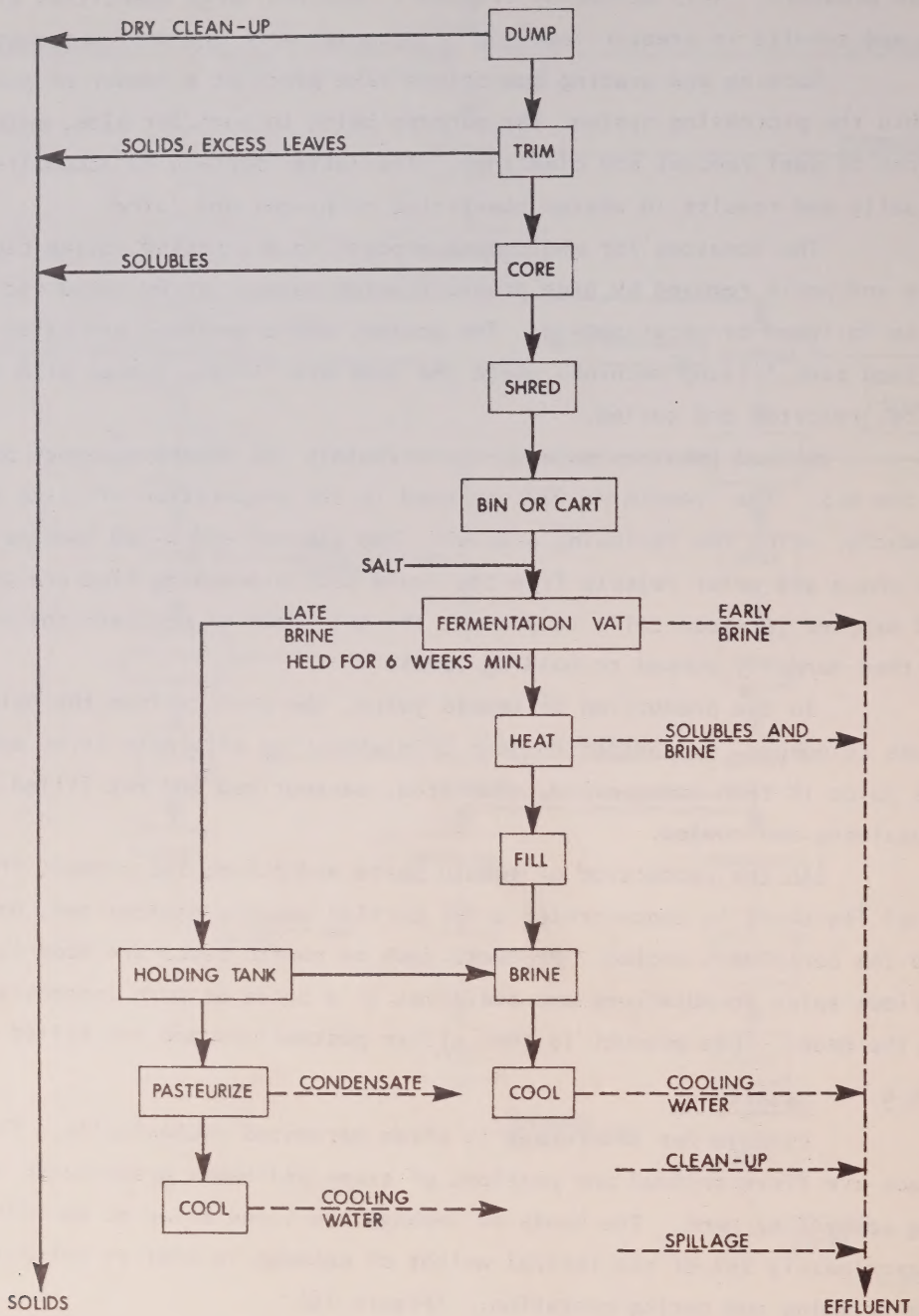


FIGURE 16. PROCESSING SCHEMATIC FLOW SHEET - SAUERKRAUT

fill of cabbage in the vat, most of this "early brine" may be withdrawn during or after the filling. This early brine is a major source of liquid waste in the cooking and fermentation processes.

A number of different kinds of bacteria, yeasts and mold spores are present on the cabbage when it arrives from the field. The addition of salt inhibits the growth of many of the undesirable organisms and the juice drawn from the shredded cabbage by the salt assists in the formation of conditions favouring the growth of lactic acid bacteria.

Fermentation is considered to be complete when the acidity expressed as lactic acid reaches 1.55%. The time required varies with the temperature and normally ranges from four to eight weeks. The sauerkraut is then removed and packaged; the product can be held in a vat for periods up to two years without spoilage, but once opened, the tank is normally emptied without delay.

The excess juice is drained off from the bottom of the tank and is retained as fill brine in canning the sauerkraut juice. The "late brine" is very high in BOD_5 , COD and suspended solids. When it is disposed of, it represents an important source of liquid waste.

Sauerkraut is heated to 82 - 85°C prior to filling in cans. Brine is added to the cans which are retorted, rinsed and cooled.

3.3.10 Pickles and relishes

Cucumbers are generally harvested by hand but there is a trend towards the use of mechanized methods. The cucumbers are delivered either to salting stations or to food processing plants, as soon as possible after picking. The cucumbers are unloaded and washed with fresh water. They are then mechanically sized, placed in bins and processed immediately or stored in a cooler for not longer than a few days.

Fresh whole dills are tightly packed in containers with whole spices and covered with hot or cold dill liquid vinegar, salt and water. The containers are capped, pasteurized and cooled promptly. Other fresh pack styles of pickles are sliced or chopped, washed and packed in liquid or syrup depending on the type required. The packaging operation is the same as that for processed pickles. (Figure 17)

In preparing processed pickles, cucumbers are stored in wooden vats in 15 - 20% salt brine. During the fermentation process, salt and brine are added, and the brine generally recirculated from the bottom of the tank

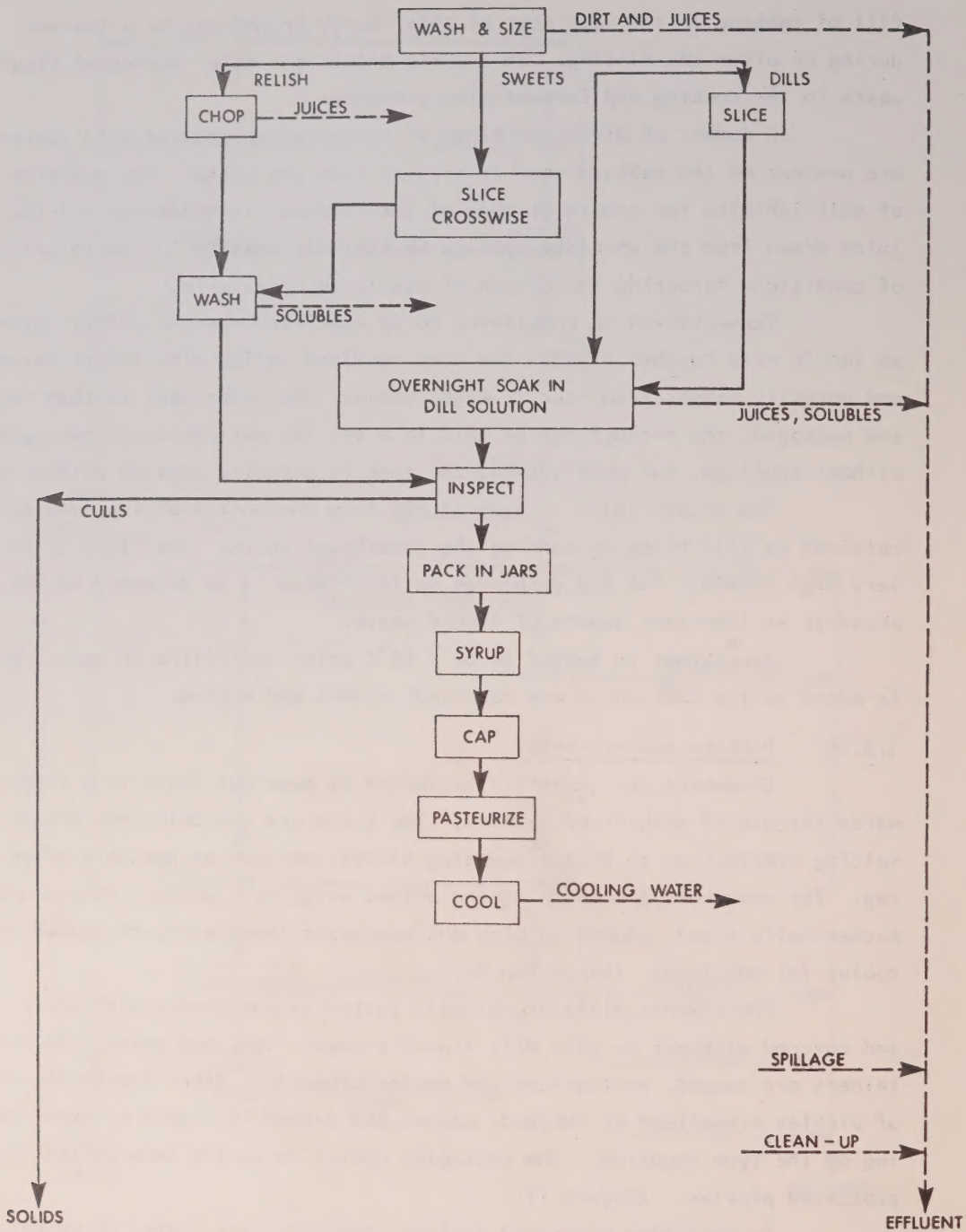


FIGURE 17. PROCESSING SCHEMATIC FLOW SHEET - FRESH PICKLES

to the top. The fermentation process takes approximately three to six months.

Various types of sweet pickle products are made from processed pickles by a number of operations. These include leaching most of the salt using fresh water, conditioning with alum and tumeric, addition of vinegar and sweetening, using sugar. The 15 - 18% salt in cured pickles is reduced to approximately 3% by at least two changes of water, the water being heated in the last change to increase the rate of leaching. Whole pickles pass into vats for impregnation with vinegar and syrups. In contrast, pickles for the production of chips and relish are sliced to the required thickness, washed and packed into jars, covered with vinegar and syrup prior to capping, pasteurizing and cooling. (Figure 18)

Sour pickles are obtained in a similar manner, except that the pickles are impreganted with a vinegar-herb mixture containing only a small quantity of sugar. Dill pickles are obtained in a similar manner, by the addition of dill herb during fermentation or by the addition of dill flavoured vinegar, at a later stage. (Figure 18)

3.3.11 Jams, jellies and preserves

Most processors buy the fruits in preprocessed bulk packs because of the short harvesting seasons and the physical characteristics of the finished product. Bulk packs consist of fruit juices used for jelly processing or fruit pieces used in jam production. Fruit concentrate is also used for jelly preparation. Jelly is generally preprocessed in frozen containers of various sizes; in contrast, apricots, peaches, grapes and plums maybe canned or frozen. (Figure 19)

The preprocessed fruit is dumped into stainless steel mixing tanks, allowed to thaw and heated. The setting or jelling of jams and jellies requires pectin, sugar acid and water in specific relationships to each other. Sugar in the form of corn syrup or sucrose, water and pectin are added to the tank and blended thoroughly.

The mixture is vacuum cooked to prevent degradation in the form of discoloration or the development of off flavor and the fruit is concentrated to a specified gravity.

The mixture is drained to holding tanks where acid (in the form of citric, tartaric, malic, phosphoric or lactic acid) is added to reduce

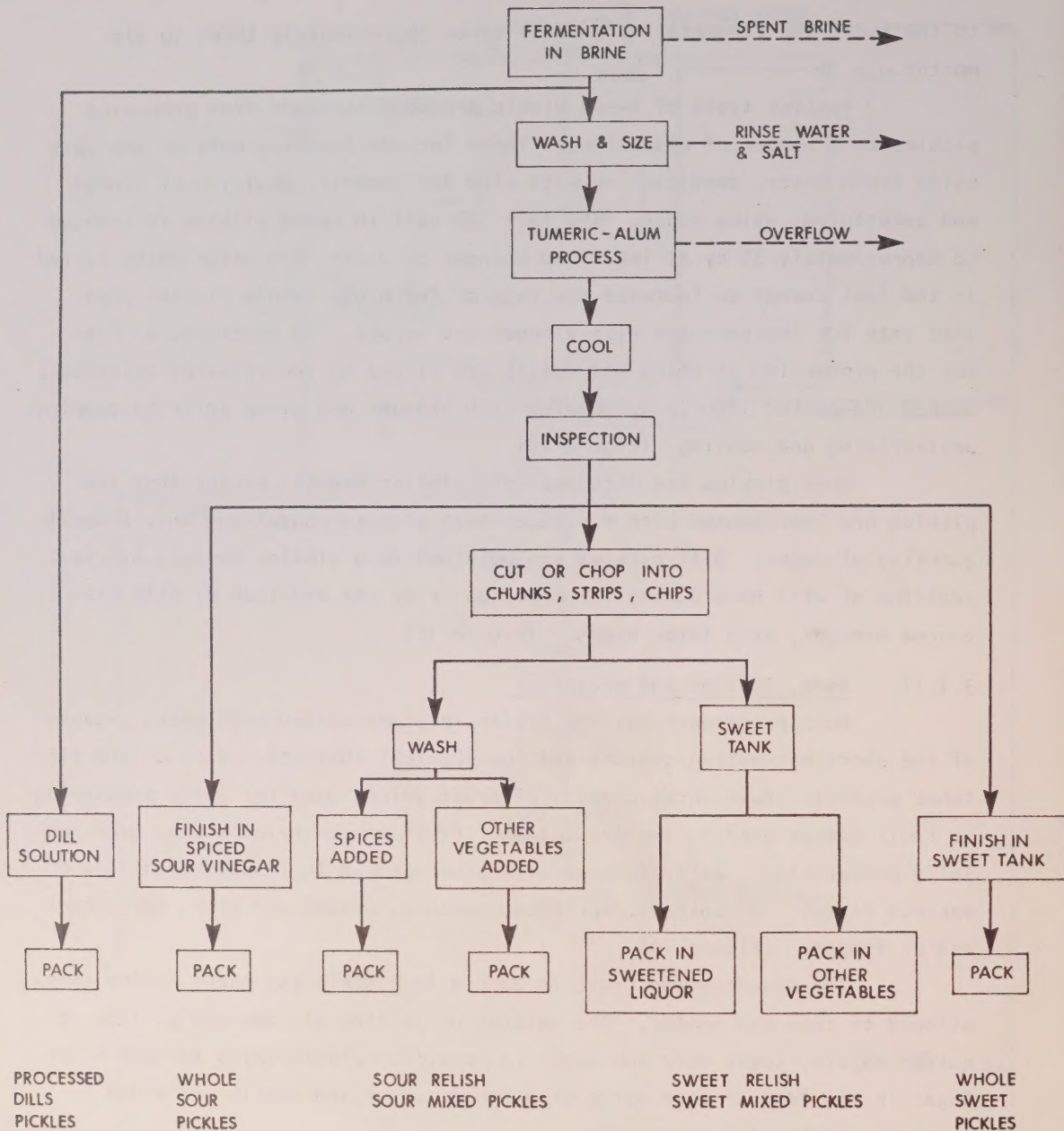


FIGURE 18. PROCESSING SCHEMATIC FLOW SHEET - PROCESSED PICKLES

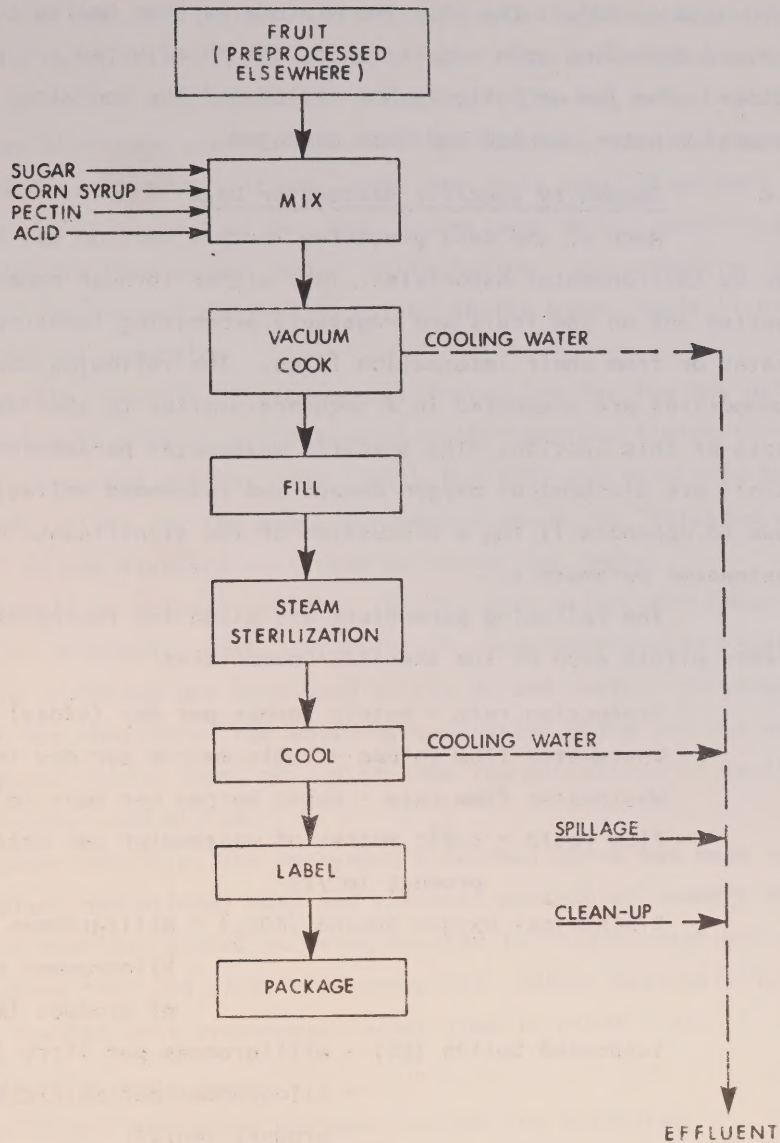


FIGURE 19. PROCESSING SCHEMATIC FLOW SHEET - JAMS AND JELLIES

the pH below the critical value of 3.6. Citric acid is the most common acid used to adjust the pH. The mixture is then heated to 77 - 88°C, homogenized depending upon requirements, the pH adjusted and pumped to the filler. The jam or jelly is hot filled and the container held hot for several minutes, cooled and then packaged.

3.4 Commodity Specific Wastewater Data

Much of the data presented in this section has been made available by Environmental Associates, Inc. either through recent work they have carried out on the fruit and vegetable processing industry in the United States or from their information files. The following data for specific commodities are presented in a sequence similar to that used in previous parts of this section. The specific wastewater parameters considered in detail are biochemical oxygen demand and suspended solids; reference is made to Appendix II for a discussion of the significance of these and other wastewater parameters.

The following parameters are given for representative groups of plants within each of the specific commodities:

Production rate - metric tonnes per day (t/day)

Wastewater flow volume - cubic metres per day (m^3 /day)

Wastewater flow rate - cubic metres per hour (m^3 /hr)

Flow ratio - cubic metres of wastewater per metric tonne of product (m^3 /t)

Biochemical Oxygen Demand (BOD_5) - milligrammes per litre (mg/l)
- kilogrammes per metric tonne of product (kg/t)

Suspended Solids (SS) - milligrammes per litre (mg/l)
- kilogrammes per metric tonne of product (kg/t).

Following the technique used by the U.S. Environmental Protection Agency and Environmental Associates, Inc., the log mean values given in this report present the logarithmic average of the data for the indicated parameter. The "maximum" and "minimum" values given are not the absolute value of the data sets but statistical values equal to one standard deviation above and below the log mean.

Data distribution analysis based on the United States information indicated that the standard normal distribution model was inadequate for most cases. The range of the data was wide, and a few relatively large values tended to result in a skewed distribution. The log normal distribution model was therefore studied and found to describe the data better than the normal distribution. It was found that more than 75 percent of the flow ratio and 85 percent of the BOD_5 ratios were better described by the log distribution than by the normal distribution. Consequently, the log normal distribution was adopted to establish the waste loads within each sub-category or commodity.

Generally, the U.S. Environmental Protection Service has utilized the log mean value as a basis for determining 1977 maximum limits for flow, BOD_5 and total suspended solids. The limits for 1983 are generally based on the "minimum" values for the above parameters which, as indicated above, are equivalent to one standard deviation below the log means.

It should be pointed out that the log mean values are lower numerically than the arithmetic mean. As a result, some controversy regarding the use of this technique has developed in the United States. However, the log mean value was considered the most representative value and the best value for the typical waste loads generated from the processing of various fruit and vegetable commodities.

Wherever possible, the data base discussed above has been supplemented by in-plant operational data and relevant wastewater summary data. Those data have been designated as being related to "representative" plants. It should be noted that the term "representative" refers basically to the plants having typical unit processes, rather than to plant size.

3.4.1 Apples and apple sauce

Significant wastewater streams include the following:

1. Apple wash water recirculated and dumped every eight hours.
2. Wash water used after peeling and including apple transport.
3. Water used in slicing and slice transport.
4. Water used in the deaerating and cooking processes.
5. Water used in clean-up.

An indication of the relative quantities of the volumes of water used in these subprocesses and the relative contributions to BOD_5 and suspended solids loadings is shown in Table 1. It should be noted that the data presented in Table 1 are based on a single set of samples taken at one plant producing 76.3 tonnes per day.

Raw waste summary data are presented in Table 2 for apple juice processing and for "apple products", the latter including the production of both slices and sauce. These data are for total screened wastewater. Inspection of Table 2 shows the wide variation in BOD_5 and suspended solids unit waste loadings for the plants investigated; for example, the BOD_5 unit waste loadings range from 3.93 to 25.4 kilogrammes/tonne for "apple products". These data and other similar data for other commodities are used in Section 7 to assess the operation of Canadian plants.

It should be pointed out that this variation in data is typical for the industry and is associated with differences in in-plant processing techniques, production rates, etc.

The wastewater materials balance summary given in Table 3 gives a breakdown of the total effluent flow and total waste loadings between the major sources of wastewater. Inspection of this table shows apple washing requires 7% of the total flow and contributes only 3% of the BOD_5 . Slicing and peel-core processing steps contribute 10 - 15% of the flow and 10 - 15% of the effluent loadings. In contrast, the principal source of wastewater flow and effluent loadings was from clean-up operations in this particular plant. It should be pointed out that the water consumption at this plant was $4.4 \text{ m}^3/\text{t}$ of product for complete processing which is low compared to most other commodities.

3.4.2 Peaches, pears and apricots

Significant wastewater streams in the processing of these three commodities include the following:

1. Overflow from dump tanks and various fluming operations.
2. Overflow and periodic dumping of caustic peelers and wash tanks.
3. Can cooling water.
4. Clean-up of spills and equipment.

TABLE 1. APPLE SLICE PRODUCTION - UNIT OPERATION DATA

PROCESSING OPERATION	APPLE WASH	SLICING	SPRAY WASH	DEAERATION	TRANSPORT	COOK	WATER CONVEYOR	TOTAL
Flow Volume (m ³ /day)	11.4	79.5	11.4	-	322	-	90.8	507
Flow Rate (m ³ /hr)	0.54	6.3	0.63	0.16	26.8	0.16	7.6	42.1
Flow Ratio (m ³ /t)	0.084	0.992	0.099	0.025	4.22	0.025	1.19	6.6
BOD ₅ (mg/l)	620	2750	90.0	18200	600	10800	1260	1140
(kg/t)	0.052	2.73	0.010	0.450	2.53	0.268	1.50	7.5
SS (mg/l)	38	102	13	1770	20	415	73	50
(kg/t)	0.004	0.102	0.002	0.044	0.085	0.011	0.087	0.332
pH	6.9	6.1	7.5	4.2	7.0	4.8	7.4	6.9

NOTE: Production 76.3 tonnes per day.

Symbols are defined in Appendix I

TABLE 2. WASTE SUMMARY DATA - APPLE JUICE AND APPLE PRODUCTS

PARAMETER NO. OF PLANTS	APPLE JUICE (SCREENED WASTEWATER) 3			APPLE PRODUCTS (SCREENED WASTEWATER) 7		
	LOG MEAN	MIN	MAX	LOG MEAN	MIN	MAX
Production (t/day)	64.0	38.2	107	66.2	38.2	114
Flow Volume (m ³ /day)	178	106	299	447	98.4	1980
Flow Rate (m ³ /hr)	22.2	13.3	37.1	50.0	13.0	191
Flow Ratio (m ³ /t)	2.78	1.97	3.92	6.92	1.77	27.0
BOD ₅ (mg/l)	725	619	849	1440	663	3150
(kg/t)	2.01	1.60	2.54	10.0	3.93	25.4
SS (mg/l)	100	50	201	60	14	248
(kg/t)	0.28	0.16	0.47	0.75	0.39	1.45

NOTE: Symbols are defined in Appendix I.

TABLE 3. WASTEWATER MATERIALS BALANCE SUMMARY - APPLES

UNIT OPERATION	TOTAL FLOW (%)	TOTAL BOD ₅ (%)	TOTAL SS (%)
Wash	7	3	5
Peel/Core	14	15	15
Slice	10	12	10
Cook	4	5	5
Deaerate	1	5	5
Clean-up	64	60	60
REPRESENTATIVE PLANT*	987 m ³ /day	1066 kg/day	115 kg/day

* Total water consumption 4.44 m³/t.

3.4.2.1 Peaches. A comparison of wastewater volumes and loadings resulting from the utilization of wet peel and dry peel methods is given in Table 4. Rinse water characteristics for the two methods are given in Table 5. These data show the significant reduction in water use, and suspended solids and wastewater loadings which could result from the introduction of a dry peel method.

Table 6 presents unit operation waste loadings for an entire peach operation, utilizing the wet peel method. Inspection of this table shows that the maximum organic loading (expressed as Chemical Oxygen Demand - COD) is from the peel rinse, and confirms the data presented in Table 5, showing the large reduction in loadings in a dry peel system.

Table 7 presents flow rates and unit waste loadings from 15 plants; these data are presented as log mean values, and maximum and minimum values. Arithmetic average values for data from single plants are also presented for screened wastewater samples; comparison of these data with the mean values in Table 7 illustrates the wide variation between plant operations and the need to specify in-plant processing technology in discussing overall plant wastewater loadings. These aspects are discussed more fully in Section 7 of the report.

3.4.2.2 Pears. The principal source of BOD_5 and suspended solids in the waste streams is from the peeling operation as shown in Table 8. Inspection of this table shows seven kilogrammes of COD material per tonne of product result from the operation of a mechanical peeler. The effluent from the peeler contains high concentrations of lye and soluble organics and the spray wash following the peeler is also high in organics (Table 8). The major water use is in can cooling but this water is not significantly contaminated and may be reused.

Wastewater summary data are presented in Table 9 for a number of pear operations, and screened effluent data for one plant.

3.4.2.3 Apricots. In apricot processing, the dump tanks and flumes usually use recirculated water with fresh or reclaimed water makeup, and continuous overflow to the sewer. Periodic dumping of the lye peeler and overflow from the washers contribute the principle BOD_5 loading; this waste stream includes significant quantities of lye, soluble organics, peels and other fruit solids.

TABLE 4. COMPARISON OF WASTEWATER VOLUMES AND LOADINGS FROM
WET-PEEL AND DRY-PEEL METHODS [5]

PROCESS	FLOW (m ³ /t)	BOD ₅ (kg/t)	SS (kg/t)	SS (mg/l)
Wet-peel	2.17	18.5	5.2	2375
Dry-peel	0.14	5.6	1.5	9750

TABLE 5. COMPARISON OF RINSE WATER CHARACTERISTICS FOR DRY-PEEL
AND CONVENTIONAL PEELING PROCESSES [6]

PROCESS	FLOW (m ³ /t)	BOD ₅ (kg/t)	SS (kg/t)
Conventional	3.55	3.9	2.6
Dry-peel	0.38	1.4	1.0

TABLE 6. UNIT OPERATION WASTE LOADINGS FROM
A CONVENTIONAL PEACH PROCESS [7]

OPERATION	FLOW (m ³ /t)	COD (kg/t)	SS (kg/t)
Box Wash	0.417	1.0	1.0
Pit Flume	6.26	3	3
Peel Rinse	8.35	10	10
Flumes	4.17	5	1
Cooling	Mostly Reused		

TABLE 7. WASTE SUMMARY DATA - PEACHES

PARAMETER	RAW WASTE			SCREENED WASTEWATER	SCREENED WASTEWATER
NO. OF PLANTS	15 LOG MEAN	MIN	MAX	1 (3) AVERAGE	1 (2) AVERAGE
Production (t/day)	215	54.8	841	35.2	195
Flow Volume (m ³ /day)	2580	432	15400	125	8180
Flow Rate (m ³ /hr)	140	28.8	684	13.3	-
Flow Ratio (m ³ /t)	12.5	6.19	25.2	3.41	42.0
BOD ₅ (mg/l)	1200	745	1940	3900	833
(kg/t)	15.5	9.54	25.3	13.3	35.0
SS (mg/l)	410	163	1030	1140	-
(kg/t)	4.3	2.2	8.4	3.9	-

NOTE: Symbols are defined in Appendix I.

Number of samples given in brackets.

TABLE 8. UNIT PROCESS WASTE LOADINGS FROM A PEAR PROCESS [8]

OPERATION	FLOW (m ³ /t)	COD (kg/t)	SS (kg/t)
Mechanical Peeler	0.154	7.0	0.2
Brine Tank Overflow	0.025	1.1	0.2
Trimming	0.067	1.6	0.1
Rinsing	0.050	3.3	0.2
Chopping	0.025	0.1	0.1

TABLE 9. WASTE SUMMARY DATA - PEARS

PARAMETER NO. OF PLANTS	RAW WASTE 9			SCREENED EFFLUENT 1 (15) AVERAGE
	LOG MEAN	MIN	MAX	
Production (t/day)	174	116	259	253
Flow Volume (m ³ /day)	2270	900	5720	6400
Flow Rate (m ³ /hr)	82.1	17.6	382	400
Flow Ratio (m ³ /t)	13.4	6.68	26.7	25.5
BOD ₅ (mg/l)	1900	1340	2690	1900
(kg/t)	26.2	12.9	53.1	48.4
SS (mg/t)	333	216	512	318
(kg/t)	5.40	2.02	144	8.11

NOTE: Symbols are defined in Appendix I.

Number of samples are given in brackets.

Can wash water may contain solids and solubles from syrup and fruit spilled on the outside of the can. Can cooling water is generally one of the largest wastewater volumes generated in the operation and is the main source of reclaimed water supply for reuse.

Raw waste loadings from seven apricot processing plants are presented in Table 10.

Data available on a representative plant processing pears, peaches and apricots are shown in Table 11. Inspection of this table shows the relatively high contributions of the peel and wash processing steps to the total volumetric flow and to the total waste loadings (33% and 48% respectively).

3.4.3 Cherries and plums

Significant wastewater streams in the processing of these two commodities include the following:

1. Pitting operations.
2. Washing.
3. Can cooling.

The high contribution of the cherry pitting operation to the total wastewater volume and organic loading is shown in Table 12 ($4.5 \text{ m}^3/\text{t}$ and 18.2 kg/t , respectively). In this case, organic loadings are represented by the parameter Chemical Oxygen Demand. Can cooling water is one of the largest wastewater volumes generated in the operation.

Raw waste loadings from seven cherry processing operations and three plum processing operations are presented in Table 13. Data presented in Table 14 for cherry and plum operations indicate that the chilling step is the largest source of wastewater flow (33% of the total flow) but that pitting generates the largest waste load (60% of the total BOD_5 and 55% of the total suspended solids).

3.4.4 Berries

Significant wastewater streams include the following:

1. Washing.
2. Slicing.
3. Clean-up.

TABLE 10. WASTE SUMMARY DATA - APPRICOTS

PARAMETER NO. OF PLANTS	RAW WASTE 7		
	LOG MEAN	MIN	MAX
Production (t/day)	253	141	455
Flow Volume (m ³ /day)	6780	5150	9010
Flow Rate (m ³ /hr)	324	258	407
Flow Ratio (m ³ /t)	29.3	15.6	55.1
BOD ₅ (mg/l)	363	123	1070
(kg/t)	15.2	10.5	21.9
SS (mg/l)	113	33	387
(kg/t)	1.87	3.57	6.90

NOTE: Symbols are defined in Appendix I.

TABLE 11. WASTEWATER MATERIALS BALANCE SUMMARY - PEARS,
PEACHES AND APRICOTS GROUP

UNIT OPERATION	% TOTAL FLOW	% BOD ₅	% SS
Dump Tank (Wash)	34	23	35
Halve/pit (Core)	11	17	13
Peel-Wash	33	48	42
Fill	10	5	3
Clean-Up	12	7	7
Total (Representative Plant)	8900 m ³ /day	7.6 t/day	4.2 t/day

TABLE 12. UNIT OPERATION DATA FOR A SWEET CHERRY PROCESS [8]

OPERATION	FLOW (m ³ /t)	COD (kg/t)	SS (kg/t)
Stemmer	2.4	0.4	0.1
Grader	0.08	0.3	0.1
Pitter	4.5	18.2	0.6

TABLE 13. RAW WASTE SUMMARY DATA - CHERRIES AND PLUMS

PARAMETER NO. OF PLANTS	CHERRIES 7			PLUMS 3		
	LOG MEAN	MIN	MAX	LOG MEAN	MIN	MAX
Production (t/day)	44.8	15.3	131	119	27.2	517
Flow Volume (m ³ /day)	549	129	2320	492	98.4	2580
Flow Rate (m ³ /hr)	71.3	20.0	253	27.8	6.33	122
Flow Ratio (m ³ /t)	12.8	6.6	24.9	4.10	3.20	5.26
BOD ₅ (mg/l)	1060	510	2200	1070	804	1430
(kg/t)	13.6	7.43	24.8	4.40	3.53	5.49
SS (mg/l)	73	45	117	81	40	163
(kg/t)	0.859	0.448	1.65	0.335	0.182	0.611

NOTE: Symbols are defined in Appendix I.

TABLE 14. WASTEWATER MATERIALS BALANCE SUMMARY - CHERRIES AND PLUMS

UNIT OPERATION	% TOTAL FLOW	% BOD ₅	% SS
Chill	33	5	5
Stem	13	10	15
Wash	16	15	15
Pit	28	60	55
Clean-Up	10	10	10
Total			
(Representative Plant)	1720 m ³ /day	160 kg/day	140 kg/day

Inspection of Table 15, showing the materials balance summary for miscellaneous berry processing, shows that the washing operation contributes 60% of the total BOD_5 and 70% of the total volumetric flow. Clean-up operations contribute significantly (30% of the total BOD_5) because of the sugar used in the operation. Slicing and filling operations result in some spillage but the volume is small.

Waste summary data for seven strawberry operations are given in Table 16. In addition, the data for screened effluent from one frozen process are also included for the purposes of comparison.

3.4.5 Corn

Significant wastewater streams include the following:

1. Washing.
2. Blanching.
3. Cooling water.
4. Clean-up.

The larger volumes of water originate from the washing and can cooling operations: BOD_5 levels are very low in the cooling water but may be significant in the wash water. Blanching wastes are more concentrated since the sugars and starches tend to leach rapidly from the corn.

Tables 17 and 18 present unit process data for cut corn and corn on the cob systems, respectively. Table 19 illustrates waste loadings for a cut corn kernel process. Inspection of Table 19 shows that the washers contribute the major portion of the organic and suspended solids loadings to the total effluent flow.

A wastewater materials balance summary is shown in Table 20 for a representative plant. Inspection of this table shows that the major water uses are the desilking and flotation washing operations (a total of 65% of the total flow and 35% of the total BOD_5 loading).

The raw waste characteristics of a number of corn on the cob and cut corn processes are summarized in Table 21.

3.4.6 Peas and beans (blanched vegetables)

These vegetables are grouped together because of similarities in processing techniques and in the quality of effluents produced. Significant wastewater streams in the processing of these commodities include the following:

TABLE 15. WASTEWATER MATERIALS BALANCE SUMMARY - MISCELLANEOUS BERRIES

UNIT OPERATION	% TOTAL FLOW	% BOD ₅	% SS
Wash	70	60	70
Slice	5	10	5
Clean-Up	25	30	25
Total			
(Representative Plant)	940 m ³ /day	440 kg/day	130 kg/day

TABLE 16. WASTE SUMMARY DATA - STRAWBERRIES

PARAMETER	RAW WASTE			SCREENED EFFLUENT (FROZEN PROCESS)
NO. OF PLANTS	7 LOG MEAN	MIN	MAX	1 (9)
Production				
(t/day)	49.6	23.8	103	100
Flow Volume				
(m ³ /day)	723	193	2748	2910
Flow Rate				
(m ³ /hr)	47.5	23.1	979	-
Flow Ratio				
(m ³ /t)	16.1	8.68	29.9	29.1
BOD ₅				
(mg/l)	487	256	926	176
(kg/t)	7.86	4.51	13.7	5.13
SS				
(mg/l)	153	109	216	123
(kg/t)	2.47	1.53	3.98	3.6
pH	-	-	-	7.6

NOTE: Symbols defined in Appendix I.

Number of samples in brackets.

TABLE 17. UNIT OPERATION DATA FOR A CUT CORN PROCESS [8]

OPERATION	FLOW (m ³ /t)	COD (kg/t)	SS (kg/t)
De-silk	1.36	4.4	1.2
Steam Blanch	0.18	5.1	1.5
Flotation Wash	0.20	2.6	0.8
Clean-up	0.61	1.3	0.3

TABLE 18. UNIT OPERATION DATA FOR A CORN-ON-COB PROCESS [8]

OPERATION	FLOW (m ³ /t)	COD (kg/t)	SS (kg/t)
De-silk	1.36	4.4	0.7
Steam Blanch	0.14	1.2	0.1
Cool	1.03	1.2	0.1

TABLE 19. UNIT OPERATION DATA FOR A CUT CORN KERNEL PROCESS [9]

OPERATION	FLOW* (m ³ /hr)	BOD ₅ (kg/hr)	SS (kg/hr)
Husked Corn Washer	11.3	447	18.7
Washers and Silker	30.9	260	77.5
Inspection Belt	12.3	20	5.6
Blancher	8.6	72	14.1
Filler	0.03	29	-

* Production = 350t/hr

TABLE 20. WASTEWATER MATERIALS BALANCE SUMMARY - CORN

UNIT OPERATION	% TOTAL FLOW	% BOD ₅	% SS
Desilk	45	16	12
Blanch	2	35	36
Flotation Wash	20	19	9
Cooling and Fluming	23	21	35
Clean-up	10	4	4
Total (Representative Plant)	3680 m ³ /day	6.7 kg/day	2.2 kg/day

TABLE 21. WASTE SUMMARY DATA - CORN

PARAMETER NO. OF PLANTS	RAW WASTE			SCREENED EFFLUENT 1 (7)	SCREENED EFFLUENT 1 (11)	SCREENED EFFLUENT 1 (7)
	LOG MEAN	14 MIN	MAX			
Production (t/day)	258	51.6	1290	138	-	-
Flow Volume (m ³ /day)	1330	288	6170	2730	-	-
Flow Rate (m ³ /hr)	144	80.6	256	170	-	-
Flow Ratio (m ³ /t)	6.73	1.99	22.7	20.4	-	-
BOD ₅ (mg/l)	1900	684	5280	454	-	-
(kg/t)	12.8	8.22	19.9	9.28	33.1	24.3
SS (mg/l)	570	176	1840	75	-	-
(kg/t)	4.19	2.03	8.68	1.53	8.57	8.39

NOTE: Symbols defined in Appendix I.

Number of samples in brackets.

1. Washing.
2. Blanching.
3. Cooling.
4. Clean-up.

3.4.6.1 Peas. The largest volumes of water are due to washing and can cooling. Wash water usually contains dissolved solids and dirt, but the can cooling water, having no product contact, can usually be reused. Another major source of wastewater is the blanching operation; hot water blanchers contribute significantly to plant effluents, being low in volumetric flow but high in BOD_5 loading. Condensate from steam blanchers is more concentrated but lower in volume.

Unit operation data for a pea processing plant are given in Table 22. Inspection of this table shows the washers make a relatively high contribution (136 kg/hr BOD_5 material) to the total effluent loading. Although it is difficult to relate these data to those presented in Table 23 for 30 pea processing plants, calculations based on data presented in the latter table indicate the mean total BOD_5 loading is 109 kg/hr, ranging from 53 - 276 kg/hr.

Data on screened effluent from three separate plants are also included in Table 23. Inspection of these data shows them to be within the range of values presented for the 30 plants.

3.4.6.2 Snap beans (green and wax). The cooling water makes the largest contribution to the total wastewater volume but is generally low in BOD_5 and suspended solids. In contrast, the wash water and effluent from slicing operations can contribute significantly to pollutant levels. The overflow from the hot water blanchers or condensate from steam blanchers generally contain the most concentrated organic waste loadings.

Unit operation data for a green bean process are given in Table 24. Inspection of this table shows the relatively high contribution of organic waste loadings (1.5 kg/t) from the blanching operation compared with other operations. The relatively high contribution of washing and clean-up operations to the total flow is also shown ($2.2 \text{ m}^3/\text{t}$ and $1.75 \text{ m}^3/\text{t}$, respectively).

Total plant waste loads from a number of plants processing green beans are given in Table 25. In addition, analyses of screened effluent

TABLE 22. UNIT OPERATION DATA FOR PEA PROCESS [9]

UNIT OPERATION	FLOW (m ³ /hr)	BOD ₅ (kg/hr)	SS (kg/hr)
Clipper Mill	31	65	29
Washers	19	21	3
Washers & Blanchers	17	136	5
Size Graders, Inspection Belts, Fillers	18	--	--

TABLE 23. WASTE SUMMARY DATA - PEAS

PARAMETER NO. OF PLANTS	RAW WASTE			SCREENED EFFLUENT 1 (6)	SCREENED EFFLUENT 1 (8)	SCREENED EFFLUENT 1 (8)
	LOG MEAN	30 MIN	MAX			
Production (t/day)	78.3	43.5	141	66.8	-	-
Flow Volume (m ³ /day)	1480	647	3350	1950	-	-
Flow Rate (m ³ /hr)	122	60.5	244	177	-	-
Flow Ratio (m ³ /t)	23.7	9.28	60.6	30.6	-	-
BOD ₅ (mg/l)	811	272	2420	800	-	-
(kg/t)	19.2	8.53	43.4	24.5	27.2	23.7
SS (mg/l)	231	78.9	673	344	-	-
(kg/t)	5.40	2.48	11.8	10.5	10.3	6.49

NOTE: Symbols are defined in Appendix I.

Number of samples in brackets.

TABLE 24. UNIT OPERATION DATA FOR A GREEN BEAN PROCESS

OPERATION	FLOW (m ³ /t)	COD (kg/t)	SS (kg/t)
Wash and Grade	2.2	0.6	1.0
Snip	0.08	0.1	0.04
Blanch	0.45	1.5	0.1
Clean-up	1.75	0.1	0.04

TABLE 25. WASTE SUMMARY DATA - GREEN BEANS

PARAMETER NO. OF PLANTS	RAW WASTE			SCREENED EFFLUENT 1 (2) AVERAGE	SCREENED EFFLUENT 1 (15) AVERAGE
	LOG MEAN	21 MIN	MAX		
Production (t/day)	130	66.1	257	3.13	155
Flow Volume (m ³ /day)	1800	738	4350	2820	2380
Flow Rate (m ³ /hr)	117	55.1	248	289	123
Flow Ratio (m ³ /t)	14.2	8.53	23.7	901	16.7
BOD ₅ (mg/l)	222	130	377	165	1190
(kg/t)	3.15	1.79	5.56	149	19.4
SS (mg/l)	181	86	383	15	666
(kg/t)	2.57	1.08	6.13	13.5	11.1
pH	-	-	-	7.9	-
Temperature (°C)	-	-	-	27.8	-

NOTE: Symbols defined in Appendix I.

Number of samples in brackets.

from two single plants are included for the purpose of comparison. Inspection of these data indicates the two plants are well outside the range of the 21-plant data for BOD_5 loadings.

3.4.6.3 Lima beans. Water from blanchers, washers and size graders contribute substantially to the BOD_5 and suspended solids loadings in the effluent. Cooling water flow makes a significant contribution to the total flow but is relatively free from contaminants and is sometimes discharged without treatment. When froth flotation cleaners are used (to remove loose skins and other extraneous material), the oil solution is recirculated.

Wastewater summary data for lima bean operations are given in Table 26. Organic and suspended solids loadings for two other plants are also included in this table for the purposes of comparison. It is noted that the loadings from these two plants are outside the ranges given for the other four plants. No other information was available to assess the noted variations.

3.2.6.4 Other blanched vegetables. Asparagus produces a very low waste load in both BOD_5 and suspended solids. The principle sources of wastewater loadings from pumpkin-squash operations arise from the washing, chopping, finishing and pressing operations.

Raw waste summary data are presented in Table 27 for asparagus and pumpkin-squash for a number of plants.

A wastewater materials balance summary is presented in Table 28 for blanched vegetable commodities. Inspection of this table shows blanching contributes 31% of the total BOD_5 and 18% of the suspended solids loadings. Washing is the other major contributor (26% of the total BOD_5 and 59% of the suspended solids). Comparison of the total effluent flow given ($3900 \text{ m}^3/\text{day}$) shows it to be within the ranges given in Tables 23, 25, 26 and 27 for specific vegetables in this group.

3.4.7 Beets and carrots

Significant wastewater streams in the processing of these two commodities are as follows:

1. Washing.
2. Trimming and peeling.

TABLE 26. WASTE SUMMARY DATA - LIMA BEANS

PARAMETER NO. OF PLANTS	RAW WASTE			SCREENED EFFLUENT 1 (5)	SCREENED EFFLUENT 1 (4)
	LOG MEAN	4 MIN	MAX		
Production (t/day)	61.1	22.6	165	-	-
Flow Volume (m ³ /day)	2150	984	4690	-	-
Flow Rate (m ³ /hr)	207	101	425	-	-
Flow Ratio (m ³ /t)	35.4	18.3	68.7	-	-
BOD ₅ (mg/l)	314	102	968	-	-
(kg/t)	13.5	8.06	22.6	105	61.2
SS (mg/l)	220	82.5	584	-	-
(kg/t)	7.78	4.16	14.5	43.7	61.0

NOTE: Symbols are defined in Appendix I.

Number of samples in brackets.

TABLE 27. WASTE SUMMARY DATA - ASPARAGUS AND PUMPKIN/SQUASH

PARAMETER NO. OF PLANTS	ASPARAGUS 6			PUMPKIN/SQUASH 5		
	LOG MEAN	MIN	MAX	LOG MEAN	MIN	MAX
Production						
(t/day)	65.3	34.5	124	105	18.2	607
Flow Volume						
(m ³ /day)	2250	420	12100	1220	375	4010
Flow Rate						
(m ³ /hr)	336	96.5	1170	72	22.8	228
Flow Ratio						
(m ³ /t)	35.0	11.8	104	12.0	4.60	30.9
BOD ₅						
(mg/l)	67	25	179	1220	302	4140
(kg/t)	2.34	0.77	7.08	14.7	8.45	25.7
SS						
(mg/l)	70	43	114	544	185	1600
(kg/t)	3.75	2.38	5.92	6.55	4.18	10.3

NOTE: Symbols are defined in Appendix I.

TABLE 28. WASTEWATER MATERIALS BALANCE SUMMARY -
BLANCHED VEGETABLE COMMODITIES

UNIT OPERATION	% TOTAL FLOW	% BOD ₅	% SS
Washing	41	26	59
Cutting	7	11	4
Blanching	2	31	18
Cooling	20	15	10
Clean-up	30	17	9
Total (Representative Plant)	3900 m ³ /day	4.4 t/day	1.2 t/day

3. Slicing/dicing.
4. Blanching.
5. Cooling.
6. Clean-up.

3.4.7.1 Beets. Trimmed portions of beets are generally transported dry from the inspection belts since the use of flumes can increase both waste volumes and pollution loadings. Wet peeling processes are also a major source of waste loads but dry peeling techniques have been used in beet processing. Data for washing, and blanching and peeling operations are shown in Table 29 and indicate the relatively high contribution of blanching and peeling to the total waste loading (31.8 kg/t expressed as COD) compared with wash water (0.9 kg/t COD). A summary of wastewater characteristics for seven beet processing plants is shown in Table 30. In this table, the total BOD_5 loading ranges from 20.0 - 39.4 kg/t.

3.4.7.2 Carrots. Wastewater strengths vary considerably, depending on the degree of peel removal and the use of abrasive peelers or polishers. Water from the peel removal operation and blancher effluents are the principal sources of BOD_5 and suspended solids, but the initial washing operation generates large volumes of wastewater and high levels of settleable solids.

Wastewater summary data are presented for a number of carrot processing plants in Table 31.

A wastewater material balance summary for beets and carrots processing is shown in Table 32. Inspection of this table shows that the peeling and blanching operations make the largest contribution to the total waste loading (68% BOD_5 and 42% suspended solids), and that the washing and peeling operations make the largest contribution (64%) to the total wastewater flow. Comparison with Tables 30 and 31 shows the representative plant illustrated in Table 32 is large compared with these beet and carrot processors.

3.4.8 Tomatoes

Significant wastewater streams include the following:

1. Overflow from dump tanks and various fluming operations.
2. Overflow and periodic dumping of caustic peelers and wash tanks.

TABLE 29. DATA FOR TWO UNIT OPERATIONS IN A BEET PROCESSING PLANT [8]

UNIT OPERATION	FLOW (m ³ /t)	COD (kg/t)
Wash	1.17	0.9
Blanch and Peel	2.75	31.8

TABLE 30. WASTE SUMMARY DATA - BEETS

PARAMETER NO. OF PLANTS	RAW WASTE 9		
	LOG MEAN	MIN	MAX
Production (t/day)	177	128	244
Flow Volume (m ³ /day)	1320	526	3260
Flow Rate (m ³ /hr)	103	63.0	167
Flow Ratio (m ³ /t)	7.57	3.23	17.7
BOD ₅ (mg/l)	3710	1420	9700
(kg/t)	28.1	20.0	39.4
SS (mg/l)	1350	372	4880
(kg/t)	9.62	4.99	18.5

NOTE: Symbols are defined in Appendix I.

TABLE 31. WASTE SUMMARY DATA - CARROTS

PARAMETER NO. OF PLANTS	RAW WASTE			SCREENED EFFLUENT 1 (2)
	LOG MEAN	6 MIN	MAX	
Production (t/day)	111	63.5	195	54.7
Flow Volume (m ³ /day)	950	447	3940	212
Flow Rate (m ³ /hr)	82.4	33.4	204	26.1
Flow Ratio (m ³ /t)	12.2	5.83	25.7	4.22
BOD ₅ (mg/l)	1180	644	2160	2190
(kg/t)	14.5	10.7	19.5	9.25
SS (mg/l)	636	262	1540	274
(kg/t)	7.80	2.83	21.5	1.16

NOTE: Symbols are defined in Appendix I.
Number of samples in brackets.

TABLE 32. WASTEWATER MATERIALS BALANCE SUMMARY -
BEETS AND CARROTS

UNIT OPERATION	% TOTAL FLOW	% BOD ₅	% SS
Wash	35	7	29
Peel	29	41	33
Blanch	2	27	9
Pulp, Finished	4	3	4
Cool	12	9	9
Fill, Seal	4	2	1
Clean-Up	14	11	15
Total			
(Representative Plant) 6880 m ³ /day 10 t/day 8.9 t/day			

3. Can cooling.

4. Clean-up.

In the canning of whole tomatoes, the hot lye peeling operation is a major source of alkalinity, and a major source of BOD_5 and suspended solids in the total wastewater effluent. The peeling operation is not used in the manufacture of tomato juice and concentrate, and therefore pollutant generation from the canned tomato operation is significantly higher than those from the other operations.

Unit operation data for a whole packed tomato process are given in Table 33. A wastewater materials balance summary is given in Table 34 for the processing of both peeled tomatoes and tomato products. Inspection of this table shows that for this plant, the initial cleaning operation resulted in the largest contribution of BOD_5 loading and wastewater flow (55% and 50%, respectively).

Waste summary data for 17 tomato processing plants are presented in Table 35. In addition, screened effluent data from two other plants are presented for the purposes of comparison. Both these plants are small compared with the group of 17 plants.

3.4.9 Sauerkraut

Significant wastewater streams include the following:

1. Early brine.
2. Late brine.
3. Soak water.

Early brine has a high BOD_5 concentration (up to 20,000 mg/l). The volume produced depends on the plant operation and the sauerkraut processing rate. Late brine is the highest in BOD_5 concentration, 40,000 mg/l or greater; the volume is also variable, depending on the individual plant operation and the market demand for sauerkraut juice.

Between seasons, the wooden fermentation vats are filled with soak water to prevent shrinkage and collapse until ready for use. This water is high in terms of total volume but is low in concentrations of wastes. It should be pointed out that soak water is not required in fibre glass lined or concrete vats. Cabbage cutting and transportation are dry operations and clean-up is generally carried out under dry conditions, with the cutting and coring equipment washed at regular intervals.

TABLE 33. UNIT OPERATION DATA FOR A WHOLE-PACK TOMATO PROCESS [7]

UNIT OPERATION	FLOW (m ³ /t)	BOD ₅ (kg/t)	SS (kg/t)
Dump	250	1	0.3
Box Wash	20	1	0.1
Wash	450	1	0.3
Flume	20	1	0.3
Peel Rinse	600	3	1.3
Sort and Can	100	0.05	0.05

TABLE 34. WASTEWATER MATERIALS BALANCE SUMMARY - TOMATOES*

UNIT OPERATION	% TOTAL FLOW	% BOD ₅	% SS
Clean	50	55	65
Peel	7	7	6
Pulp	13	10	5
Fill, Seal	20	10	10
Plant Clean-up	10	18	14
Total (Representative Plant)	3070 m ³ /day	1.4 t/day	1.8 t/day

* Processing both whole-pack and other products.

TABLE 35. WASTE SUMMARY DATA - TOMATOES

PARAMETER NO. OF. PLANTS	RAW WASTE			SCREENED EFFLUENT 1 (1)	SCREENED EFFLUENT 1 (1)
	LOG MEAN	17 MIN	MAX		
Production (t/day)	1010	413	2470	169	234
Flow Volume (m ³ /day)	8440	2730	26100	382	1250
Flow Rate (m ³ /hr)	608	443	842	-	-
Flow Ratio (m ³ /t)	9.24	5.47	15.6	2.24	5.34
BOD ₅ (mg/l)	487	303	783	1000	1110
(kg/t)	4.66	3.16	6.85	2.25	5.90
SS (mg/l)	600	280	1280	691	553
(kg/t)	6.17	2.89	13.2	1.55	2.95

NOTE: Symbols are defined in Appendix I.

Number of samples in brackets.

Unit operation data for the sauerkraut operation are given in Table 36; these data show that the early brine and the late brine make the major contributions to effluent loadings (1.55 and 3.80 kg/t BOD₅, respectively). Wastewater characteristics for the packaging operations are not shown in this table. It should be pointed out that wastes are expressed in terms of shredded cabbage rather than raw product entering the processing plant.

A wastewater materials balance summary is presented in Table 37; inspection of this table shows the relatively low contribution of the cleaning operation to the total flow and effluent loading (10%), and the relatively high (60%) contribution of the filling and canning operations.

Waste summary data for two plants processing sauerkraut are shown in Table 38. In addition, data from single plants are shown for the purpose of comparison.

3.4.10 Pickles and relishes

Significant wastewater streams include the following:

1. Spent brine
2. Wash water.
3. Clean-up.

Table 39 illustrates the relative contribution of the spent brine and the clean-up operations to the total effluent loading (14.6 and 2.5 kg/t BOD₅, respectively). This is confirmed by data presented in Table 40: spent brine contributes 80% of the BOD₅ and 65% of the suspended solids loadings to the total effluent loading.

A wastewater summary for eight pickle and relish plants is presented in Table 41.

3.4.11 Jams, jellies and preserves

Significant wastewater streams include the following:

1. Cooling water.
2. Spillage.
3. Clean-up.

Spills result in a low volume, high strength waste because of the high sugar content of the product. Clean-up waste typically generates the high

TABLE 36. UNIT OPERATION DATA FOR A SAUERKRAUT PROCESS [10]

UNIT OPERATION	VOLUME (m ³ /t)	BOD ₅ (kg/t)	TOTAL SOLIDS (kg/t)	SODIUM CHLORIDE (kg/t)
Vat Soak Water	0.92	0.06	0.45	0
Vat Wash Water	0.008	0.002	0.02	0
Early Brine	0.17	1.55	10.3	5.9
Late Brine	0.13	3.80	7.8	3.6

TABLE 37. WASTEWATER MATERIALS BALANCE SUMMARY - SAUERKRAUT

UNIT OPERATION	% TOTAL FLOW	% BOD ₅	% SS
Fermentation	30	30	30
Can and Fill	60	60	50
Clean-Up	10	10	20
Total (Representative Plant)	655 m ³ /day	670 kg/day	160 kg/day

TABLE 38. WASTE SUMMARY DATA - SAUERKRAUT

PARAMETER	RAW WASTE	SCREENED EFFLUENT	SCREENED EFFLUENT
NO. OF PLANTS	2 RANGE	1 (4)	1 (1)
Production			
(t/day)	13.2 - 193	-	19.6
Flow Volume			
(m ³ /day)	387 - 946	-	458
Flow Rate			
(m ³ /hr)	490 - 131	-	56.9
Flow Ratio			
(m ³ /t)	5.27 - 29.9	-	23.2
BOD ₅			
(mg/l)	792 - 1670	186	1500
(kg/t)	4.18 - 50.0	-	34.8
SS			
(mg/l)	60.6 - 2380	90	1390
(kg/t)	0.32 - 71.1	-	32.2
pH	- -	7.3	-

NOTE: Symbols are defined in Appendix I.

Number of samples are given in brackets.

TABLE 39. UNIT OPERATION DATA FOR A PICKLE PROCESS

UNIT OPERATION	FLOW (m ³ /t)	BOD ₅ (kg/t)	SS (kg/t)
Pickle Brine Tanks	2.8	14.6	0.4
Clean-up	6.1	2.5	0.9

TABLE 40. WASTEWATER MATERIALS BALANCE SUMMARY -
PICKLES AND RELISHES

UNIT OPERATION	% TOTAL FLOW	% BOD ₅	% SS
Shot Water*	38	10	15
Brine	15	80	65
Wash & Size	37	8	15
Clean-up	10	2	5
Total (Representative Plant)	640 m ³ /day	1130 kg/day	225 kg/day

* Shot water discharged only during fresh pack season.

TABLE 41. WASTE SUMMARY DATA - PICKLES AND RELISHES

PARAMETER NO. OF PLANTS	RAW WASTE ⁸		
	LOG MEAN	MIN	MAX
Production (t/day)	44.3	19.9	101
Flow Volume (m ³ /day)	625	284	1400
Flow Rate (m ³ /hr)	81.4	40.7	153
Flow Ratio (m ³ /t)	14.3	8.68	21.1
BOD ₅ (mg/l)	1510	1130	2000
(kg/t)	21.6	16.2	28.6
SS (mg/l)	209	84.0	520
(kg/t)	2.99	1.33	6.70

NOTE: Symbols are defined in Appendix I

strength waste loads on a consistent basis due to kettles and cookers which must be maintained in accordance with good sanitation practices. Can and jar cooling water may be recirculated by passing the water through a cooling trap.

A waste water materials balance summary for jams and jellies is given in Table 42. Waste summary data for two processing plants are presented in Table 43.

TABLE 42. WASTEWATER MATERIALS BALANCE SUMMARY - SECONDARY
PROCESSING OF FRUITS FOR JAMS, JELLIES AND PRESERVES

UNIT OPERATION	% TOTAL FLOW	% BOD ₅	% TOTAL SUSPENDED SOLIDS
Clean-up	100	100	100
Total (Representative Plant)	380 m ³ /day	795 kg/day	255 kg/day

TABLE 43. WASTE SUMMARY DATA - JAMS AND JELLIES

PARAMETER NO. OF PLANTS	RAW WASTE 2 RANGE
Production (t/day)	7.90 - 77.3
Flow Volume (m ³ /day)	34.1 - 144
Flow Rate (m ³ /hr)	1.85 - 5.54
Flow Ratio (m ³ /t)	1.81 - 4.30
BOD ₅ (mg/l)	1150 - 4410
(kg/t)	4.93 - 7.96
S S (mg/l)	394 - 711
(kg/t)	0.550 - 3.06

NOTE: Symbols are defined in Appendix I.

4 IN-PLANT PROCESS CONTROL

4.1 Introduction

Fundamental unit operations utilized in the fruit and vegetable processing industry were discussed in Section 3; these included harvesting, washing and rinsing, and in-process operations such as peeling and blanching. These operations were discussed in general terms since they are common to many of the plants processing specific fruits and vegetables. Variations in the unit operations were discussed to appropriate points in the presentation of the outline of each commodity process.

The purpose of this section is to outline techniques and technology currently in use to reduce total plant wastewater flows and pollutant loadings. Specific areas where research and developmental work are currently being carried out are discussed, and illustrated with examples of pilot work and full scale experimental systems, where appropriate. Each commodity is not discussed separately since the methods are, in general, applicable to more than one commodity.

In-plant control of process effluent is discussed within the framework of the following major areas:

1. General water and waste management.
2. Water consumption and water recycle.
3. In-plant modifications.

4.2 General Water And Waste Management

Plant management can play a significant role in water conservation. The education of plant employees in conservation practices could result in significant quantities of water being saved, and in financial savings if water is purchased. In addition, reduction in water consumption potentially reduces the total pollutant loading and also reduces the hydraulic loading on the plant waste treatment facility. Thus, water consumption should be an integral part of the plant wastewater control program, and every point of water use within the plant should be examined to determine where water may be reused or conserved.

One possible approach to water conservation would be to install recording devices at various usage points. During the initiation of a water control program, these devices would pinpoint major usage processes, plant

areas, and/or operations. With the installation of control devices, consumption minimization techniques, and a general conservation program, the effectiveness of these steps could be evaluated by comparison of present and past recorded volumes of water used. As part of an on-going water conservation program, periodic checks of daily data with historical usage data would identify areas experiencing water use higher than normal. These areas could be re-assessed to determine the reason or reasons for increased use, and whether or not additional control techniques should be incorporated.

A number of ways to reduce significantly the water consumption in the plant, and thus reduce operating and treatment costs, are discussed briefly below.

1. Hoses are frequently left running all day, even if they are not being used in clean-up. Spring loaded shut-off valves on the hoses would reduce the water consumption significantly.
2. Low volume, high pressure nozzles rather than low pressure sprays should be used for clean-up.
3. Unnecessary water overflow from equipment should be avoided and water flows should be stopped when the equipment is not in use. Automatic fresh water make-up valves should be provided.
4. The use of flumes to transport the product or solid waste should be avoided in the cases where the material can be transferred effectively by dry methods.
5. Cooling water consumption should be the minimum required to accomplish the necessary cooling.
6. "Clean" wastewater streams, such as cooling water, defrost water and rain water, not requiring further treatment before discharge, should bypass the plant wastewater system.
7. Good housekeeping practices should be enforced within the plant area for the control of spills, spoilage and trash, the basic aim being to employ dry cleanup and avoid disposal of excess solid waste into the liquid waste streams.
8. Solid waste handling is an integral part of the water and waste management program. Solid waste contact with the liquid waste streams should be avoided where possible and, where this

is not feasible, the waste should be screened; continuous removal of the screenings is desirable to avoid excessive leaching of solubles from the separated solids by the liquid waste stream.

4.3 Water Consumption and Water Recycle

The reuse of treated wastewater will result in a reduction in the total wastewater flow; however, there are financial and sanitary constraints associated with the reuse of wastewater in a food processing plant. Theoretically, excellent quality water can be obtained after primary and biological treatment, followed by filtration, carbon adsorption and chlorination; however, the large variations in wastewater strengths and flows present difficult operational problems and can result in an effluent of variable quality. It is not anticipated that wastewater treated by these methods would be of drinking water quality standards required in the final in-plant processes; however, it could be used in other operations being carried out earlier in the processing line. Potable water probably could be obtained by reverse osmosis treatment following the above treatment system; the economic feasibility of total water reuse following this advanced treatment has apparently reached the demonstration stage in the fruit and vegetable processing industry.

A recent publication by the National Canners Association [1] includes a comparison of studies dealing with the reuse of water in the various phases of processing fruits and vegetables. These studies were undertaken primarily to establish the feasibility of multiple water use and are outlined in Table 44. Recent reports published on the treatment of water for reuse in the fruit and vegetable industry were discussed in the same report [1] and are summarized in Table 45. Inspection of Tables 44 and 45 shows the extent of the research which has been carried out into methods for water reuse and water treatment in the fruit and vegetable processing industry.

The National Canners Association has produced a water economy "check list" which is reproduced as Table 46. This table gives the process operations or the equipment used in the industry which are major water users. It also indicates whether or not the water from specific equipment may be reused, and the source of water for reuse in the specific equipment; for example, any process wastewater can be used for fluming wastes but the waste fluming water

TABLE 44. REUSE OF WATER IN FRUIT AND VEGETABLE PROCESSING [1]

PROCESS	
Recirculation	Reuse for drain flush
Conservation	Cut usage in process
4 stage counter-flow	In pea canneries
Recirculation	Cooling water for washing, fluming, reuse screened flume water
Recirculation	--
Conservation	Tomato washing studies
Conservation	Reduction in peeling, washing, cleaning
Recirculation	Hydraulic system, bacteria count
Reuse	Reuse refrigeration and uncontaminated process water
Reuse	Can cooling and flume water
Recycling	Process brine
Countercurrent	Reuse in preceding wash and flume
Recycling	Reuse for washing
Triple-loop water economy circuit	--
Reuse	Lye rinse and process water as makeup
Counterflow	In tomato, sweet potato processing
Recirculation	Reuse volume per year

TABLE 45. TREATMENT OF WATER FOR REUSE IN PROCESSING OPERATIONS [1]

TREATMENT	PARAMETER STUDIED
Activated carbon adsorption	Organic removal
Activated carbon adsorption	Organic removal
Activated carbon adsorption	Organic removal
Activated carbon	Dissolved organics removal
Activated carbon	Reconditioning brine
Activated carbon adsorption	--
Air stripping	Ammonia removal
Biological denitrification	Nutrient removal
Brine disposal	--
Chemical oxidation	Refractory organic materials removed
Chemical oxidation	--
Chemical oxidation	Dissolved inorganics
Chlorination	--
Chlorination	--
Coagulation-sedimentation	Suspended solids removal
Coagulation-sedimentation	Suspended solids and dissolved solids removal
Disinfection	--
Distillation	Inorganic and organic removal
Distillation	Inorganic removal
Electrodialysis	--
Electrodialysis	Demineralize secondary effluent
Electrodialysis	Inorganic removal
Electrodialysis	Dissolved inorganics removal
Freezing	--
Freezing	Inorganic removal
Ion exchange	--
Ion exchange	--
Ion exchange	--
Ion exchange	Dissolved inorganics removal
Ozone sterilization	--
Ozone treatment	--
Ozone treatment	Reduction of COD
Precipitation	Nutrient removal
Reverse osmosis	--
Reverse osmosis	Inorganic removal
Reverse osmosis	Dissolved inorganic removal
Reverse osmosis	--
Reverse osmosis	--

TABLE 46. NATIONAL CANNERS ASSOCIATION WATER ECONOMY CHECK LIST **

OPERATION OR EQUIPMENT	MAY RECOVERED WATER BE USED?	MAY WATER FROM THIS EQUIPMENT BE REUSED ELSE- WHERE IN PLANT?	SOURCE OF WATER FOR REUSE IN EQUIPMENT*
1. Acid dip for fruit	yes	no	Can coolers
2. Washing of product			
A. First wash followed by 2nd wash	yes	yes*	Can coolers
B. Final wash of products	no	yes*	
3. Flumes			
A. Fluming of unwashed or unprepared product (peas, pumpkin, etc.)	yes	yes*	Can coolers
B. Fluming partially prepared product	yes	yes*	
C. Fluming fully prepared product	no	yes	
D. Any fluming of wastes	yes	no	Any wastewater
4. Lye peeling	yes	no	Can coolers
5. Product-holding vats; product covered with water or brine	no	no	
6. Blanchers - all types			
A. Original filling water	no	no	
B. Replacement or make-up water	no	no	

TABLE 46. (Continued)

OPERATION OR EQUIPMENT	MAY RECOVERED WATER BE USED?	MAY WATER FROM THIS EQUIPMENT BE REUSED ELSE- WHERE IN PLANT?	SOURCE OF WATER FOR REUSE IN EQUIPMENT*
7. Salt brine quality graders followed by a fresh water wash	yes	Only in this Equipment	
8. Washing pans, trays, etc. A. Tank washers - original water	no	no	
B. Spray or make-up water	no	no	
9. Lubrication of product in machines such as pear peelers, fruit size graders, etc.	no	yes*	Can Coolers
10. Vacuum concentrators	yes	in this equipment after cooling and chlorination	
11. Washing empty cans	no	no	
12. Washing cans after closing	yes	yes	Can Coolers
13. Brine and syrup	no		
14. Processing jars under water	yes	for processing	Can Coolers and processing waters

TABLE 46. (Continued)

OPERATION OR EQUIPMENT	MAY RECOVERED WATER BE USED?	MAY WATER FROM THIS EQUIPMENT BE REUSED ELSE- WHERE IN PLANT?	SOURCE OF WATER FOR REUSE IN EQUIPMENT*
15. Can Coolers			
A. Cooling canals			
1. Original water	no		
2. Make-up water	yes		
B. Continuous cookers where cans are partially immersed in water			Waters from these coolers may be re- used satisfactorily for cooling cans after circulating over cooling towers, if careful attention is paid to proper control of replace- ment water, and to keeping down bacterial count by chlorination and frequent cleaning.
1. Original water	no		
2. Make-up water	yes		
C. Spray coolers with cans not immersed in water	yes		
D. Batch cooling in retorts	yes		
		This water may be reused in other places as indicated.	
16. Clean-up purposes			
A. Preliminary wash	yes	yes*	Can coolers
B. Final wash	no	no	
17. Box washers	yes	no	Can coolers

* A certain amount of water may be reused for make-up water and in preceding operations if the counterflow principle is used with the recommended precautions.

** Townsend, C.T. and Somers, I.I. "How to Save Water in Canneries", Food Industries, 21, W11 - W12 (1949).

cannot be reused in any other operation. In contrast, only fresh water must be used for fluming finished product but the resultant wastewater can be reused elsewhere in the plant.

It is evident that this "check list" would be a good point to start in developing a water management program for a specific processing plant.

These tables illustrate the multiple use of water in the commercial processing of fruits and vegetables. Specific areas where water conservation and water reuse are practiced and where developmental work is being carried out are now discussed.

4.3.1 High pressure-low volume clean-up

There is apparently little information available on water reduction attributable to changes in cleaning systems in the fruit and vegetable processing industry. Recent data reported by Crosswhite [11] show a reduction in clean-up water consumption from 420 to 170 m³/day by conversion to a high pressure system in a poultry plant.

It is assumed, for purposes of discussion, that implementation of this technique in the fruit and vegetable industry would result in a 25% reduction of water used in clean-up.

4.3.2 Dry collection and transport of product and solid wastes

Commodities are transported within the plant between processing operations using conveyor belts, flumes, pneumatic transport or boxes carried by fork lifts. Water fluming is commonly used because it serves the multiple purpose of washing, cooling and transport. There are a number of advantages to this method in that it is generally economic and does not result in the product being damaged. However, large quantities of water are used and there is a tendency for soluble organics to be leached into the wastewater stream. While it is impractical to replace completely this method of transport, a conveyor belt or pneumatic transport can be used in some instances for a number of commodities.

An example where this mode of transportation could be retained is in the pea processing operation. Flumes or pumps are the preferred method of transport in order to maintain product quality. However, considerable

water savings may be realized by using recirculated water or water from another operation. In addition, negative air systems are replacing water transport in many plants, where practicable.

Cooling water can be reused in conjunction with transportation by conveyor. The conveyors utilize high pressure, low volume sprays of cooling water at periodic intervals to wash the belt and prevent build up of organic slime. Pneumatic transport may also be used to move solid wastes such as seeds, pits and pulp to prevent these solids from entering the wastewater stream. A pneumatic system has been used in a tomato product plant to remove residue from the finishing operations. Another example in tomato processing is the use of roller conveyors, fitted with water sprays, to transport the tomatoes from the dumptank to the size graders. In this method, the tomatoes are constantly rotated facilitating sorting and removal of culls, and cleaning by the exposure of all surfaces to the sprays.

4.3.3 Counter-current flow of washwater

In counter-current systems, potable water is contacted with the clean processed product and is then recirculated to operations further back in the process which do not require such high quality water. Thus the product is exposed sequentially to cleaner water as it progresses along the processing line.

Counter-current systems are used extensively in the food processing industry. Water savings depend on the commodity and the quantity of water that can be recycled. An example can be taken from corn processing, illustrated in Table 20. This table shows that 20% of the total plant water flow was used in the flotation wash. In this particular plant, the implementation of counter-current flow back to the desilking operation could result in a water use reduction equivalent to approximately $740 \text{ m}^3/\text{day}$.

It is assumed that there would be no reductions in levels of BOD_5 and suspended solids by the introduction of this technique of water reduction.

4.3.4 Water recycle in the same operation

The use of cooling towers greatly reduces the volume of water used for cooling cycles such as those in the retorting of tins or glass containers. Conventional retorting is carried out by "batch" or "continuous" methods; in the latter process, the containers being heated are rotated through pressurized cookers followed by low pressure or atmospheric coolers. When used in

conjunction with cooling towers, the water can be reused for several weeks or longer, or alternatively, recycled to various fluming and first-wash operations.

An example is the use of cooling towers to condense evaporated water in the tomato evaporation and concentration operations, followed by the reuse of this water for condenser cooling.

In a number of processes, the water used in the initial wash of the vegetables or fruits is recycled with some overflow and make-up.

Assuming no treatment of the wastewater stream is required before recycling, the extent of recycle can range from 50 to 75% of the process operation water flow. For example, in a plum/cherry operation such as that illustrated in Table 14, 50% recycle of the pitter water and 100% recycle of the stemmer water would result in an overall reduction in water consumption of 27%.

4.4. In-Plant Process Modifications

4.4.1 Commodity dry cleaning

Dry cleaning of tomatoes has been demonstrated on a pilot scale [12]; this system consisted of a water dump tank, a rubber disk cleaning unit and a final low volume, high pressure spray. The function of the dump tank was to cushion the unloading tomatoes, to remove lumps of soil and to saturate the "smear" soil on the tomatoes. The rubber disk cleaning unit consisted of a series of soft spinning rubber disks which removed smear soil and stems.

Water consumption in the dump tank was $0.3 \text{ m}^3/\text{t}$ and in the disk cleaning unit was $0.02 \text{ m}^3/\text{t}$ of tomatoes. The effluent loading was 0.25 kt/t expressed as COD material. These figures are much lower than those associated with the conventional tomato cleaning process which requires water quantities in the range of $1.7 - 5.4 \text{ m}^3/\text{t}$.

Although no full scale dry cleaning units are known to exist, the method is considered to be an economically feasible option which can greatly reduce water use in this high volume operation [18].

4.4.2 Dry peeling

In the "dry" caustic peeling system, the caustic softened peel is removed by the mechanical abrasion of rotating rubber disks, rather than by high pressure water sprays as in the conventional "wet" method. The peel

waste is discharged separately as a slurry to avoid contamination of the normal plant effluent, and is ultimately disposed to landfill. In some cases, the peel residue can be processed for utilization as cattle feed.

Originally designed and developed for use on white potatoes, the dry peel system has found commercial application in the peeling of other root crops such as beets, sweet potatoes, and carrots. In addition, commercial units are being used for peeling tomatoes and peaches.

A comparison of wastewater volumes and effluent loadings resulting from the use of wet and dry peel methods was given in Tables 4 and 5 of this report. These data apply to peach processing and showed that the wastewater volume decreased from 2.17 to 0.14 m³/t and the BOD₅ loadings reduced from 18.5 to 5.6 kg/t. Recent pilot studies on beet peelers [16] showed a reduction in BOD₅ loadings from 2.5 to 0.6 m³/t.

In the peeling of tree fruits by dry caustic methods, the removal of the softened peel is effected by the wiping action of soft rubber disks, in contrast to the hard stub-like disks used for root vegetables. In a particular study [18], the dry peeling of peaches, pears and apricots was investigated and wastewater parameters developed and compared for the dry and wet caustic peeling methods. In peeling cling peach halves, there was a reduction in water consumption of 93%, a reduction of 70% in the effluent loading expressed as COD, and a reduction of 71% in the suspended solids loadings. However, an important economic consideration was the loss of fruit with the peel. Based on this study, it appeared that less apricot was lost with the peel in the dry process compared with the wet process (peeling losses 3.7 - 8.3%, and 6.4 - 9.3%, respectively), while the loss during the processing of peaches and pears was approximately the same for both peeling processes.

4.4.3 Low water consumption blanching

Blanching is an important step in the processing of many fruits and vegetables; a discussion of the rationale behind blanching and an outline of the methods currently in use were discussed in Section 3 of this report.

The pollutant loads from blanching are a significant portion of the total load in the effluent stream during the processing of certain vegetables. For example, blanching contributes 35% of the total BOD₅ for corn (Table 20) and 31% of the total BOD₅ for blanched vegetables (Table 28).

Considerable research has been carried out recently on a number of alternate methods designed to minimize the waste generated in the blanching operation. Three methods which have been demonstrated on a pilot scale but not on full scale are the following:

1. Individual quick blank (IQB).
2. Hot gas.
3. Microwave.

4.4.3.1 Individual quick blanch (IQB). This method has been extensively evaluated since 1970, primarily under the sponsorship of the United States Department of Agriculture. The IQB blanching system was investigated by Lund [13] using peas, corn, lima beans, carrots, beets, and green beans. These vegetables were blanched by this process, canned and stored.

The IQB process is a two stage operation; in the first stage, the vegetable is exposed to a heat source (condensing steam) for sufficient duration that the average temperature is in the range required for blanching (greater than 85°C); in the second stage, the vegetable is held adiabatically until thermal gradients have equilibrated and the blanching process is complete.

Less waste generation results from this process because steam condensation is limited to that required for heating the vegetable to the blanching temperature range. There is minimum tissue damage and there is no overheating.

Data are presented in Table 47 showing a comparison of waste-water characteristics for five green pea blanching methods [13]. Inspection of Table 47 shows that the effluent flow is reduced from $0.384 \text{ m}^3/\text{t}$ in a conventional type blancher to $0.146 \text{ m}^3/\text{t}$ by the IQB method when the peas are predried to 93% of the original moisture content. The IQB system appears to have great potential in replacing conventional blanching systems for a number of commodities. However, use of this method in the fruit and vegetable processing industry will depend on the economic feasibility.

4.4.3.2 Hot gas blanching. This process has been studied on pilot scale by the National Cannery Association [14]. The conclusions reached from this study were that this blanching technique accomplished the required enzyme deactivation and tissue gas removal at practical loading rates for small

TABLE 47. COMPARISON OF WASTEWATER CHARACTERISTICS FOR FIVE
GREEN PEA BLANCHING METHODS [13]

BLANCHING TREATMENT	FLOW (m ³ /t)	BOD ₅ (kg/t)	TOTAL ORGANIC NITROGEN (kg/t)	TOTAL PHOSPHORUS (kg/t)
IQB - 6.9 (a)	0.146	1.8	0.09	0.02
IQB - 0 (b)	0.225	2.6	0.13	0.04
30 sec (c)	0.209	2.5	0.13	0.03
Deep bed (d)	0.313	4.3	0.22	0.05
Pipe (e)	0.384	3.0	0.17	0.05

(a) IQB with a 6.9% weight reduction by means of predrying prior to blanching.

(b) IQB with no predrying.

(c) 30 Sec - the heat only section of IQB.

(d) Deep bed steam blanching (product charge in a layer 6.4 to 7.6 cm deep).

(e) Pipe blanching (the control/commercial method).

sized vegetables such as cut green beans or peas. Hot gas blanching of larger pieces such as corn on the cob and whole beets required longer residence times and resulted in high steam consumption. The overall quality product using this method was within the range of commercial acceptability.

Estimated capital costs for commercial scale hot gas blanchers for green beans are twice that of a hot water blancher, the estimated operating costs being 25% less than those for hot water blanching. It is considered that this system could become the most cost effective blanching method for these plants in the future, with increased wastewater treatment costs. The general estimated total cost of hot gas blanching for most commodities was of the order of 45% greater than the hot water method, excluding savings in wastewater disposal costs.

4.4.3.3 Microwave blanching. A comparison of microwave blanching with hot gas, steam and hot water blanching systems [15] showed that a microwave blanching system reduced blanching waters up to 99% compared with a hot water system but capital costs were too high for the system to be economically feasible for most seasonally operated plants.

4.4.4. Brine recycle

Brine recycle is applicable to pickles and sauerkraut. In this process, the brine is concentrated in an evaporator and the slurry incinerated to remove organics. The salts are then reused. Based on data given in Table 37 (sauerkraut) and Table 40 (pickles and relishes), spent brine contributes 10% and 80% of the total BOD_5 , respectively.

4.5 Water Reduction Summary

Table 48 presents a summary of some of the major in-plant process controls, modifications and techniques, previously discussed in this section, which could effect a reduction in water consumption. For comparative purposes and to provide a general indication of savings in water consumption, an attempt has been made to assign percentage flow reductions to be realized with the implementation of the various techniques and technologies. It should be noted that the percentage figures are subjective, being greatly dependent on the particular plants' situation to which the reduction methods may be applied.

TABLE 48. SUMMARY OF WATER REDUCTION TECHNIQUES AND TECHNOLOGIES

TECHNIQUE/TECHNOLOGY DESCRIPTION	ESTIMATED PERCENTAGE REDUCTION IN WATER CONSUMPTION
(a) General Water and Waste Management (i.e. automatic shut-off valves on hoses, good housekeeping, control of spillages, etc.)	5% reduction in total plant water usage.
(b) High Pressure - Low Volume Clean-up	25% reduction in water used for clean-up.
(c) Dry Collection and Transport of Product and Waste Solids	Essentially elimination of water use.
(d) Counter Current Flow of Washwater	Essentially elimination of the specific process water use if suitable quality and quantity of water available from other pro- cesses.
(e) Washwater Recycle in Same Operation	50 to 75% reduction in the wash- ing water usage.
(f) Commodity Dry Cleaning	Approximately 80% [12].
(g) Dry Peeling	In the order of 80 to 90% less than the total wet peeling con- sumption.
(h) Steam Blanching	Reduction in water use of approx- imately 50% or more over conven- tional hot water system.

5

WASTE TREATMENT TECHNOLOGY

5.1

Introduction

Fruit and vegetable processing wastes contain high concentrations of organics and suspended solids, and can be treated by those processes used in the treatment of municipal wastewaters. In most cases the processing wastes are nutrient deficient, that is, they lack sufficient nitrogen and phosphorus for biological treatment; thus the addition of nitrogen and phosphorus compounds is often required. In addition, the unit processes employed in commodity production may produce an acid or alkaline effluent stream, resulting in fluctuations in the pH of the final effluent. Neutralization by acid or base may be required prior to biological treatment. Details of nutrient addition, pH control and flow equalization are now considered.

5.1.1

Nutrient addition

Minimum quantities of nitrogen and phosphorus are required for cell synthesis in the biological oxidation process in order to maintain optimum process efficiency. The effectiveness of the removal of soluble BOD_5 , and the liquid-solid separations will be impaired if a proper nutritional balance is not maintained.

The nitrogen and phosphorus concentrations required are process and commodity specific and should be determined by laboratory or field investigations. In general, the nitrogen and phosphorus required for the biological oxidation process can be related to the quantity of BOD_5 removed. A $BOD_5:N:P$ ratio of 100:5:1 will give adequate quantities of nutrients. The extent of nutrient deficiencies in fruit and vegetable processing wastes is shown in Table 49 for those commodities applicable to the Canadian Industry.

The effects of nutrient deficiencies are apparent in the operation of activated sludge plants, particularly those treating wastes containing large quantities of carbohydrates. Since most of the nitrogen found in food processing wastes is in the organic form which is not readily available for microorganism growth, a greater amount of supplemental nitrogen is needed than the figures given in Table 49 would indicate.

TABLE 49. AVAILABLE NUTRIENTS IN FRUIT AND VEGETABLE EFFLUENTS [2]

COMMODITY	BOD ₅ :N:P RATIO
Peas	100:6.0:0.7
Lima Beans	100:5.4:0.6
Beans	100:4.4:0.8
Sauerkraut	100:4.0:0.5
Tomatoes	100:4.0:0.6
Squash	100:3.7:0.7
Beets	100:3.1:3.9
Corn	100:2.8:0.5
Carrots	100:2.3:0.5
Cherries	100:1.7:0.2
Apricots	100:1.6:0.2
Strawberries	100:1.6:0.3
Peaches	100:1.4:0.3
Pears	100:1.0:0.01
Pickles	100:1.0:0.2
Plums	100:0.6:0.1
Jams & Jellies	100:0.1:0.01

5.1.2 pH control

The pH of the effluent from fruit and vegetable operations is very variable, being a function of the product, the plant, and time. Reported values of pH for fruit and vegetable processing effluents are given in Table 50.

Neutralization will generally be required for those plants processing naturally acid foods (tomatoes), those using a caustic peeling process (peaches, etc.), and those using brine (sauerkraut). Canneries discharging to a municipal system do not normally neutralize the wastes.

The most reliable neutralization system consists of two or three mixing tanks in series to which an acid (sulphuric) or a base (lime or caustic) is added. For reasonably constant acidic flows, a simpler method is to use a column of limestone chips. A number of problems inherent in automatic pH control have been outlined in a recent publication by the U.S. Environmental Protection Agency [2]. These include the variability in pH and flow in a non-related manner, and problems associated with mixing the neutralizing agent with the effluent.

5.1.3 Flow equalization

Control of surges in effluent flow is normally not required as a pretreatment measure. However, if variations in flow can be smoothed out and accidental spills contained and controlled, the control of effluent pH will be improved and shock loadings to biological treatment systems will be minimized. Variations in instantaneous flow are such that the maximum flow may be four times the minimum value; these may be smoothed out using a surge tank having a capacity approximately 10 - 20% of the total daily flow volume. Settled solids may be a significant problem in a tank of this size and therefore the tank should be stirred or some means provided for their removal.

The wastewater from plants located in large cities is usually discharged to the municipal sewerage system for treatment with domestic wastewaters. Provided sufficient capacity is available to accommodate the organic loading from the industry, combined treatment is a good strategy, enabling all or a portion of the nutrient requirements for the wastes to be met from the excess nitrogen and phosphorus present in domestic wastewater.

TABLE 50. pH OF FRUIT AND VEGETABLE EFFLUENTS [1]

PRODUCT	RANGE	pH	MEDIAN
Sauerkraut	3.6-6.8		5.0
Apples	4.1-8.2		5.3
Lima Beans	5.7-7.0		5.9
Corn	3.9-8.0		6.4
Cherries	5.2-7.9		6.4
Snap Beans	5.2-8.6		6.5
Pumpkin/squash	4.2-7.2		6.6
Peas	4.9-9.2		6.6
Tomatoes	4.5-11.3		6.6
Beets	5.6-11.9		8.0
Carrots	7.4-10.6		8.2
Peaches	6.2-10.6		9.6

In smaller communities, the combined treatment of domestic and fruit and vegetable wastes should be evaluated by a rigorous cost benefit analysis. It should include a comparison of separate industrial treatment with pretreatment by the industry to ensure that the most technically and economically feasible system is employed.

Waste treatment processes which have been used in practice or investigated on a pilot scale include the following:

1. Physical Separation:
screening,
settling,
flotation,
chemical precipitation.
2. Biological Treatment:
anaerobic lagoons,
aerobic lagoons,
trickling filters,
activated sludge,
rotating biological contactors.
3. Effluent Polishing:
spray irrigation,
effluent filtration.
4. Solid Waste Treatment and Disposal:
land fill,
by-product production,
flotation,
centrifugation,
vacuum filtration.

Each of these treatment techniques is now considered.

5.2 Physical Separation

5.2.1 Screening

Screening is used for the following reasons:

1. To separate solids from the waste stream which would otherwise require degradation or removal in subsequent processes.
2. To avoid clogging problems in mechanical equipment.
3. To remove material which has value as by-product before it is degraded.

Screening is an effective and economical method of separating discrete materials such as trimmings, rejects, pits or peels. The need for screening and the type and size of screen employed is determined by the nature of the material contained in the wastes. In some cases, screening should be avoided if there is a possibility that pulpy, wet solids might disintegrate and result in significant additional organic loading on the biological treatment process. The additional loading occurs because the organic material dissolves more rapidly in the finely divided state.

There are three types of screening systems normally used:

1. Stationary screens.
2. Vibrating screens.
3. Rotating screens.

5.2.1.1 Stationary screens. Primary screening usually consists of a bar screen similar to those used in a municipal treatment plant. The function of this type of screen is to remove any large foreign objects inadvertently added to the waste flow to avoid damage to downstream unit processes.

The bars are 0.3 to 0.6 cm wide and are set at 30° to 60° to the horizontal in the influent channel; the centre to centre spacing ranges from 1.3 to 5.1 cm. The screen loading and channel width are designed to maintain a flow velocity of 0.6 m/sec to prevent solid particles settling out. The bar racks are generally followed by smaller mesh screens (20 to 40 mesh, that is, centre to centre wire spacings of 0.06 to 0.13 cm). In some applications a concave shaped screen employing high velocity pressure-feeding is used to handle slurries containing fatty or fibrous suspended material.

Fine mesh screens may be constructed of wedge wires; new developments in screening consist of the use of synthetic cloth (polyester, nylon, and polyethylene). Synthetic cloth media are manufactured in sizes down to 5 to 10 micron openings and have good resistance to blinding.

5.2.1.2 Vibrating screens. Motorized screens operate continuously and discharge solids continuously. These devices are being used more frequently

since fewer clogging problems are experienced and a drier and more compact product is obtained.

Screen sizes range from several meshes to the inch (0.25 to 1.0 cm openings) to 150 mesh wire cloth (0.02 cm centre to centre wire spacing). Vibrating screens with 20 meshes to the inch (0.127 cm centre to centre spacings) are in common use.

Screen loadings vary from 1.5 to 5.4 kg/m³ and the screened wastes usually contain 70 - 96% moisture [1].

Vibrating screens operate between 900 to 3600 rpm; the screen has a total travel between 0.08 and 1.27 cm in a circular, straight line or three dimensional path. A series of smaller screens is apparently more effective than a single larger unit.

Vibrating screens are particularly effective for the removal of tomato seeds and other similar discrete particles in fruit and vegetable wastes.

5.2.1.3 Rotating screens. In the use of a rotary screen, the wastewater enters at one end and discharges solids at the other. The liquid flows outward through the stainless steel cloth or perforated metal plate and is collected in an effluent box located below the screen. External spray nozzles continuously clean the screen which is driven by external rollers. Screen sizes are similar to those utilized in vibrating screen systems.

The function of screening is to remove suspended material from the waste stream. The percentage removal of solids ranges from 2% to 79% of the applied suspended solids loading, depending upon the commodity being processed and the unit processes involved. Suspended solid removal efficiencies for different types of screens used on several commodities are given in Table 51.

Design variables for screening processes include the following:

Wastewater characteristics:

- flow rate,
- discrete particle dimensions,
- particle concentration,
- particle shape,
- particle consistency.

TABLE 51. SUSPENDED SOLIDS REMOVAL EFFICIENCIES [1]

SCREEN TYPE	SCREEN SIZE *	MESH SIZE	PRODUCT	% SUSPENDED SOLID REMOVAL
Oscillating	0.025	100	beet, carrot	2%
Oscillating	0.105	24	potato, carrot	60%
Oscillating	0.051	50	potato, carrot	21%
Vibrating	0.254	10	beet, carrot	44%
Vibrating	0.254	10	potato, carrot	60%
Vibrating	0.058	48	fruit, tomato	32%
Rotary	0.091	28	tomato	79%

* Centre to Centre spacing in cm.

Physical features:

- channel area,
- screen inlet and outlet conditions,
- screen material,
- screen motion,
- frequency of cleaning.

5.2.2 Settling

Although primary settling is not normally applied to the total plant waste flow, it may be applied to reduce the organic loading on biological treatment systems in those plants where levels of suspended solids are high. Gravity sedimentation may be applied effectively to particular processes such as fluming raw commodities.

In the case of root crop processing, the rinse water usually contains high concentrations of inorganic soil particles which settle with a high velocity and which produce a dense settled sludge (20 - 30% solids). In contrast, fruit and vegetable processing operations, such as lye peeling, produce wastewater exhibiting poor settling characteristics. In many cases such as pea, peach, and pear processing, the wastes are high in dissolved organic material but contain little suspended material.

Laboratory column settling tests may be carried out to determine the suspended solids concentrations at various depths as a function of time. These tests are useful in determining the feasibility of primary settling and in developing design criteria for tank depth, solids storage and weir overflow rates.

Concrete or steel tanks having circular or rectangular configurations are generally used for the settling process. In circular clarifiers, the influent normally enters via a central baffled stilling well with upflow to a peripheral overflow weir. Bottom rotating sludge collector mechanisms transport the settled solids to a central well where sludge pumps deliver the sludge to the dewatering and recovery, or disposal system. Continuous rectangular clarifiers usually provide a well distributed flow across the width of the tank at one end, with liquid effluent overflow weirs set on effluent channels at the opposite end of the tanks. Chain driven bottom sludge collectors deliver settled sludge to a storage hopper normally located at the influent end of the tank.

The overflow or surface settling rates used in the primary settling of fruit and vegetable processing wastes range from 25 to 60 m³/day/m² [2]. Side wall depths of 2.75 to 3.66 m are recommended to permit sludge storage and to allow sludge thickening to take place. Minimum detention times of 40 to 50 minutes are usually recommended.

The efficiency of primary sedimentation of fruit and vegetable processing wastes depends on commodity but in most cases results in at least a 40% reduction in suspended solids and 17 to 30% reduction in BOD₅, based on raw waste loadings. Settling ponds are often used to remove soil particles from root crop rinse waters. The ponds are usually 3.7 to 5.5 metres deep to permit complete storage of one season's settled solids. It is particularly important in the operation of settling tanks that the residence time of the solids is sufficiently short to prevent the development of anaerobic conditions and associated floating sludge problems.

5.2.3 Flotation

The dissolved air flotation technique consists of air injection at approximately 80 psi into the wastewater contained in a pressurized vessel. When the effluent is reduced to atmospheric pressure, the liquid is supersaturated with air which is evolved from solution as tiny bubbles. As the bubbles rise through the waste, they become attached to suspended material and oil and grease which float to the top as a scum or froth. A surface skimmer is used to collect the solids. The addition of alum, lime, ferric salts and polyelectrolytes assists coagulation of the waste into flocs which are easily separated by flotation. Flotation can be achieved by subjecting recycled flotation tank effluent plus a portion of the inflow, or the total waste flow, to air injection under pressure.

This process has not been used extensively for pretreatment prior to biological treatment but has great potential for future use. It is particularly useful for process effluents which are difficult to settle and contain high concentrations of colloidal material or oil and grease. The flotation technique produces a relatively dense sludge, requires short detention times, and is very efficient in terms of the removal of suspended solids, and oil and grease.

Experimental investigations on a pilot plant or laboratory scale are required to develop design criteria for the following parameters:

1. Air to solids ratio.
2. Hydraulic loading ($\text{m}^3/\text{min}/\text{m}^2$).
3. Solids loading ($\text{g}/\text{hr}/\text{m}^2$).
4. Chemical type and optimum dosage.

Typical values for the removal of suspended solids determined from pilot plant investigations are shown in Table 52. Vacuum flotation of fruit and vegetable wastewaters has also proven successful in pilot scale testing: aerated wastewater subjected to a slight vacuum resulted in the removal of 77 - 98% of the suspended solids in tomato, pear, string bean, asparagus, and spinach processing wastes [1].

5.2.4 Chemical precipitation

Addition of chemical coagulants such as lime, alum, iron salts, and polyelectrolytes prior to settling produces a floc which greatly enhances the sedimentation of suspended material. Typical values for the removal of BOD_5 and suspended solids for various commodities range from 15 to 42% and 75 to 82%, respectively [1]. Chemical precipitation removal efficiencies for screened fruit and vegetable wastes are shown in Table 53.

Chemical precipitation is often carried out in "fill and draw" reactors which can be carefully controlled. However, dosages of chemical coagulants are usually much greater than those for municipal wastes because of the higher suspended solids concentrations. Small scale laboratory testing is usually required to develop process design criteria.

Chemical precipitation has had only limited application to date but has considerable potential for future installations, particularly for pretreatment prior to discharge to municipal treatment works.

5.3 Biological Treatment

5.3.1 Anaerobic lagoons

Anaerobic lagoons may be used as a primary biological process in order to reduce the organic and solids loadings on aerobic biological processes which may be more expensive to operate. The lagoons are usually 2.4 to 6.1 metres deep with 3:1 side slopes. In most cases, the detention time is between 5 - 25 days and the lagoons are designed for high surface loadings, 34 to 112 $\text{g}/\text{BOD}_5/\text{day}/\text{m}^2$.

TABLE 52. DISSOLVED AIR FLOTATION TREATMENT EFFICIENCIES

COMMODITY	% REMOVAL		REFERENCE
	SUSPENDED SOLIDS	BOD ₅	
Peach & tomato	50 - 80	-	1
Peach	84	17	1
Pumpkin	62	7	1
Peach	65 - 93	-	17
Tomato	61 - 84	-	17

TABLE 53. CHEMICAL PRECIPITATION REMOVAL EFFICIENCIES [1]

COMMODITY	COAGULANT DOSE (mg/l)	% REMOVAL EFFICIENCY	
		BOD ₅	SS
Peas	alum, 44 lime, 266	42	81
Beets & Corn	alum, 65 lime, 357	28	82
Lima Beans	alum, 39 lime, 136	15	82
Lima Beans & Spinach	alum, 22 lime, 218	32	75
Beet, Tomato, Pea, Corn Sauerkraut	lime, alum, ferric salts, zinc chloride 700 - 2520	33 - 75	--
Tomato	lime, 40 - 50	50	--

The operation depends on the activity of anaerobic bacteria which degrade organic materials in the absence of oxygen to form organic acids, methane, ammonia, hydrogen sulphide and carbon dioxide. The reaction is relatively slow, with an optimum temperature of approximately 33 to 35°C. However, there are a number of advantages:

1. Low initial cost.
2. Ease of operation.
3. No energy consumption.
4. Ability to handle shock loads.
5. Low operation costs.
6. Small land area requirement.

Odours may occur periodically but this problem can be minimized by good management. In some cases plastic covers of nylon, reinforced hypalon, polyvinyl chloride or styrofoam are utilized to retain heat and odorous gases in the pond.

Anaerobic lagoons are particularly suitable for treating the high strength biodegradable wastes characteristic of the fruit and vegetable processing industry. Anaerobic ponds have achieved 85% removal of BOD_5 and suspended solids [2]. Typical values for BOD_5 removal are given in Table 54.

The ponds must be designed with sufficient sludge storage capacity such that sludge removal is required only infrequently. Treatability studies are recommended to assess sludge accumulation rates for design purposes.

The anaerobic process can be enhanced by the construction of enclosed, well mixed reaction systems. The systems consist of flow equalization tanks, anaerobic contact tanks (0.12 to 0.5 days' detention time), air or vacuum gas stripping units, and a clarifier with sludge recirculation pumps. Loadings of 2.4 to 3.2 kg BOD_5 /day/m³ have been used with a waste recycle rate equal to 30% of the average daily flow to achieve BOD_5 and suspended solids removals of 90 to 97% [3]. Methane gas produced in the process can be collected and burned. The capital and operating costs are high but the units are suitable for installations where odour emissions cannot be tolerated and where insufficient land is available for the installation of anaerobic ponds.

TABLE 54. BOD₅ LOADINGS AND REMOVAL EFFICIENCIES - ANAEROBIC LAGOONS [1]

PRODUCT	BOD ₅ (kg/day/m ³)	DETENTION (day)	BOD ₅ REMOVAL (%)
Corn	1.1 - 1.7	6 - 11.3	25 - 69
Fruit, Sewage	1.8 - 6.9	0.17 - 0.25	50 - 70
Peas	1.3 - 2.5	2.8 - 3.9	47 - 49
Peas	1.3 - 2.5	2.8 - 3.9	22 - 29
Tomatoes	0.04 - 0.16	37	98
Tomatoes, Lima Beans	31.6	2.5	40

5.3.2 Aerobic lagoons

Aerobic lagoons or stabilization ponds are the most common biological treatment system used in the U.S. fruit and vegetable industry. The types of lagoons used are seasonal retention ponds, aerobic stabilization ponds, and aerated lagoons. All these processes depend on the action of aerobic bacteria on the soluble organics contained in the waste streams.

The organic carbon is converted to carbon dioxide and bacterial cells. Algal growth is stimulated by incident sunlight which penetrates to a depth of 1 to 1.5 metres. Photosynthesis results in the production of excess oxygen which is available to the aerobic bacteria; additional oxygen is provided by mass transfer at the air/water interface.

Aerobic stabilization ponds are 0.18 - 0.9 m deep to optimize algal activity and are usually saturated with dissolved oxygen throughout the depth during daylight hours. The ponds are designed to provide a detention time of 2 to 20 days, with surface loadings of 5.5 to 22 g BOD₅/day/m².

The ponds are usually multiple cell units operated in series to eliminate the possibility of short circuiting and to permit sedimentation of dead algae and bacterial cells. The ponds are constructed with inlet and outlet structures located in positions to minimize short circuiting due to wind induced currents; the dimensions and geometry are designed to maximize mixing. These systems can achieve 80 - 95% removal of BOD₅ and approximately 80% removal of suspended solids, with most of the effluent solids discharged as algae cells.

During winter periods the degree of treatment decreases markedly as the temperature decreases and ice cover eliminates algal growth. In regions where ice cover occurs, the lagoons may be equipped with variable depth overflow structures in order that processing waste flows can be stored during the winter. An alternative method is to provide long retention storage ponds; the wastes can then be treated aerobically during the summer period prior to discharge.

Aerobic stabilization ponds are utilized where land is readily available. In regions where soils are permeable, it is often necessary to use plastic, asphaltic, or clay liners to prevent contamination of adjacent groundwater.

Typical BOD₅ removal efficiencies for fruit and vegetable wastes are given in Table 55.

TABLE 55. BOD₅ LOADINGS AND REMOVAL EFFICIENCIES - STABILIZATION PONDS [2]

PRODUCT	BOD ₅ LOADING (g BOD ₅ /day/m ²)	DETENTION (days)	BOD ₅ REMOVAL (%)
Apricots, peaches	9.9	106	96
Apricots, peaches	88	47	79
Apricots, peaches	55	78	93
Apricots, peaches	66	70	88
Cannery	525	25	40
Cannery	86	72	90
Corn		96	59
Peas	7.7	84	96
Tomatoes	69	17	74 - 81
Tomatoes	43.5	26	80 - 81
Tomatoes, citrus	73	22	74 - 75
Tomatoes, citrus	14.9	17	85 - 88

5.3.3 Facultative ponds

Facultative ponds are usually 0.9 to 1.8 metres deep. The processes involved in aerobic stabilization ponds occur in the upper layers of facultative ponds. Anaerobic bacteria operate at depths greater than one metre and are important in the degradation of organic compounds contained in the suspended solids which settle to the bottom of the ponds. Seasonal retention ponds belong to this category.

Detention times for facultative ponds range from 7 to 30 days at surface loadings of 2.2 to 5.6 g BOD₅/m². Considerably higher organic loadings and longer retention times are utilized in seasonal holding ponds which are generally deeper than two metres.

Holding pond systems can generally produce an effluent of acceptable quality for discharge to receiving streams (BOD₅ and suspended solids concentrations less than 30 mg/l and 70 mg/l, respectively). They are particularly suitable for use in conjunction with other forms of treatment such as spray irrigation, or as flow equalization basins prior to the disposal of wastes to municipal sewage treatment works.

The quality of effluent from holding ponds treating various commodities is provided in Table 56.

5.3.4 Aerated lagoons

Where sufficient land is not available for seasonal retention or aerobic lagoons, efficient biological treatment can be achieved by the use of aerated lagoons. Air is applied to these ponds by fixed or floating mechanical aerators or by compressors through air diffusers located on the bottom of the pond. The ponds are between 2.4 and 4.6 metres deep, with 2 to 10 days retention time and achieve 55 to 90% reduction in BOD₅ [1].

There are two types of aerated lagoons in common use:

1. Completely mixed (all solids are kept in suspension and only aerobic oxidation takes place).
2. Facultative-aerated lagoon (the contents of the pond only partially mixed and suspended solids settle to depths where anaerobic decomposition occurs).

Loading rates for aerated lagoons vary considerably and are determined by rigorous laboratory or pilot scale testing carried out on the raw waste.

TABLE 56. EFFLUENT QUALITY - HOLDING LAGOONS [2]

COMMODITY	POND VOLUME (m ³ x 10 ³)	NO. OF PONDS	EFFLUENT QUALITY	
			BOD ₅ (mg/l)	SS (mg/l)
Vegetables	238.6	4	6	-
Sauerkraut	36.8	3	40	-
Peas, Corn	101.5	3	28	70
Peas, Corn	118.9	3	37	7
Peas, Corn & Vegetables	194.2	4	17	22
Peas, Corn & Misc. Vegetables	15.4	1	12	18
Sauerkraut & Carrots	37.9	1	54	14
Peas, Cream Corn & Carrots	6.9	2	32	56
Sauerkraut	84.3	2	26	100

Specific BOD_5 removal rates for given commodities in an aerated lagoon under completely mixed conditions are given in Table 57.

Aerated lagoons achieve good BOD_5 removal. Levels of suspended solids in the effluent are usually high and therefore aerated lagoons are usually followed by quiescent settling to reduce the concentration of solids.

5.3.5 Trickling filters

Trickling filters, utilizing plastic media in columns 4.5 to 6.0 metres high, have been used in the treatment of high strength fruit and vegetable wastes (300 to 4000 mg/l BOD_5) [2]. High liquid recirculation rates and forced air circulation are used to achieve BOD_5 removals up to 90%.

Wastewater is distributed by rotating arms at constant rates onto the top surface of packed columns of plastic media. A biological film is formed on the media and cellular material periodically sloughs-off when the thickness becomes sufficiently great that oxygen transfer cannot occur throughout its depth and anaerobic conditions develop. Underdrains located beneath the column transport the effluent to settling tanks where the dense sludge is separated from the liquid effluent. A portion of the effluent is recirculated to seed the process with biological cells and to promote consistent sloughing.

General design criteria for trickling filters are as follows: roughing filters may be loaded at rates of $4.8 \text{ kg } BOD_5/\text{day}/\text{m}^3$ filter media and achieve BOD_5 reductions of 40 - 50%; high rate filters achieve BOD_5 reductions of 40 - 70% at organic loadings of 0.4 to $4.8 \text{ kg } BOD_5/\text{day}/\text{m}^3$; standard rate filters are loaded at 0.08 to $0.4 \text{ kg } BOD_5/\text{day}/\text{m}^3$ and achieve BOD_5 removals greater than 70%.

Both high rate and roughing filters are normally followed by additional treatment. In general they are used to reduce the loading on subsequent treatment processes because of cost and ease of operation. Limited data shown in Table 58 are principally from pilot plant operations.

5.3.6 Activated Sludge

In an activated sludge treatment system, an acclimatized, mixed, biological growth of microorganisms (sludge) is contacted with organic material in the wastewater in the presence of excess dissolved oxygen and nutrients (nitrogen and phosphorus). The microorganisms convert the soluble

TABLE 57. BOD_5 REMOVAL RATE CONSTANTS AND EFFICIENCIES - AERATED LAGOONS [1]

PRODUCT	INFLUENT (mg/l)	DETENTION (days)	k (days ⁻¹)	BOD_5 REMOVAL %
Beets	4236	1.1	0.018	98
Beets	3830	0.75	0.053	96
Carrots	1910	0.37	0.38	86
Peas	535 - 1212	12	-	76 - 97
Peas	970	0.39	0.15	94
Peas	578	0.23	0.30	93
Peas	820	5.6	0.04	78
Peas	3000 - 4400	5.5	0.044	76
Peas, Carrots	1260	0.25	0.76	81
Peaches	1650	0.16	2.9	54
Peaches	1100	82	0.00037	97
Pumpkins	1380	0.35	1.14	60
Pumpkins	2500	1.2	0.42	50 - 60
Tomatoes	-	5	0.064	68

NOTE: Fraction of BOD_5 removed = $(1 - kt)^{-1}$

TABLE 58. BOD₅ LOADINGS AND REMOVAL EFFICIENCIES - TRICKLING FILTERS [2]

COMMODITY	ORGANIC LOADING (kg/day/m ³)	BOD ₅ (mg/l)	BOD ₅ REMOVAL (%)	RECYCLE RATIO (Raw: recycle)
Corn	2.4	500 - 2000	94	1:10
Corn	1.8	-	94	1:5
Peas	2.9 - 6.7	-	25 - 37	
Peas	3.5	-	50	
Peaches	15.3	2700 - 4000	29	1:14
Peaches	36.8	2700 - 4000	44	7:14
Peaches	38.4	-	85	1:1

organic compounds to carbon dioxide and cellular material. Oxygen is obtained from applied air which also maintains adequate mixing. The effluent is settled to separate biological solids and a portion of the sludge is recycled; the excess is wasted for further treatment such as dewatering.

Activated sludge systems utilized in the fruit and vegetable industry are the extended aeration types: that is, they combine long aeration times with low applied organic loadings. The detention times are three to ten days. The suspended solids concentrations are maintained at high values to facilitate treatment of the high strength wastes.

It is usually necessary to provide nutrient addition, pH control and flow equalization prior to the activated sludge process, to ensure optimum operation. BOD_5 and suspended solids removals in the range of 95 - 98% have been achieved, using similar processes for many fruit and vegetable wastes. However, pilot or laboratory scale studies are required to determine organic loadings, oxygen requirements, sludge yields, sludge settling rates, etc. for these high strength wastes.

The following information required for the design of activated sludge systems can be obtained from bench or pilot scale experiments:

1. BOD_5 removal rate data.
2. Oxygen requirements for the degradation of organic material and the degradation of dead cellular material (endogenous respiration).
3. Sludge yield, determined from the conversion of soluble organics to cellular material and the influx of inorganic solids in the raw waste.
4. Solid/liquid separation rate; the final clarifier would be designed to achieve rapid sedimentation of solids which would be recycled or further treated. A maximum surface settling rate of $16.5 \text{ m}^3/\text{day}/\text{m}^2$ has been suggested for fruit and vegetable wastes [2].

Activated sludge systems used in the fruit and vegetable processing industry may be batch ("fill and draw") or continuous flow. The activated sludge reactors and clarifiers are often lined earthen basins rather than concrete or steel tanks, the former involving lower construction costs.

These systems are more difficult to operate than lagoon systems or trickling filters but can consistently produce a specified effluent

quality. They are particularly suited for use in locations where there is limited land available. However, operational power costs and operation and maintenance costs are relatively high.

Typical design criteria and operating conditions for activated sludge systems treating fruit and vegetable wastes are as follows [17];

- activated sludge concentration 2,000 - 4,000 mg/l,
- organic loading 0.1 to 0.5 kg BOD_5 /kg microbial solids,
- solids retention time (sludge age) 3 - 10 days,
- aeration time 16 - 48 hours, dependent on organic loading and sludge age requirements,
- depth 3.0 - 6.1 metres (2.1 m minimum),
- return sludge rate 25 - 100% of plant inflow rate.

5.3.7 Rotating biological contactors

The use of rotating biological contactors is relatively new in North America but has been utilized in Europe for a number of waste treatment applications. BOD_5 reductions up to 90% have been achieved with multi-stage units on citrus and apple processing wastes [13].

Rotating contactors consist of closely spaced flat parallel disks mounted on horizontal shafts which rotate at 1 to 6 rpm perpendicular to the direction of waste flow. The disks are partially submerged in the wastes and a biological film consisting of a mixed population of bacteria, fungi and protozoans develops on the surface of the disks. The biological film is alternately contacted with the waste and with the atmosphere for oxygen exchange. The rotational motion maintains solids in suspension and entrains air in the liquid effluent. As the biological growth increases, a portion of it separates from the disks and is settled in a clarifier.

The organic loading required for 90% BOD_5 removal is specific to the waste being treated. A high degree of treatment is possible since the contactors are designed to provide plug flow and the bacterial growth changes with distance along the contactor. The contactors may be used subsequent to roughing treatment such as anaerobic or aerated lagoons; a number of contactors in series may be used without roughing treatment.

Biological contactors can cope with fluctuating loadings and can provide consistently good quality effluent. They are relatively simple to operate, require little maintenance and consume relatively little energy.

At the present time, economic considerations of high capital cost detract from their widespread use.

5.3.8 High purity oxygen system

The high purity oxygen system consists of the same basic unit processes as those used in activated sludge, with the exception that 90% oxygen is used instead of air for aeration. The higher oxygen concentration (7 - 15 mg/l improves mass transfer from the gas to the liquid phase and permits the sludge concentration in the tank to be increased, resulting in decreases in reactor size and detention time requirements.

The design of the biological reaction system generally takes the form of a number of completely mixed tanks in series, sealed to provide a slight pressure above atmospheric. High purity oxygen is generated from air passed through packed beds of molecular sieve to separate oxygen from carbon dioxide and nitrogen. Oxygen is introduced into the treatment system at approximately 90% purity and is exhausted from the treatment system at approximately 50% purity. It is sometimes necessary to add alkali buffer for pH adjustment due to the high bacteriological activity and the production of carbon dioxide.

Although the capital costs of high purity oxygen systems are greater than those of conventional activated sludge systems, the units occupy less space and apparently produce a denser sludge which is easily settled and dewatered. These phenomena are particularly noticeable on wastes containing high concentrations of carbohydrates [3].

Design parameters for high purity oxygen systems have the following approximate values:

- activated sludge concentration 3,000 - 5,000 mg/l,
- organic loading 0.5 - 0.7 BOD₅/kg microbial solids,
- solids retention time (sludge age) 6 - 10 days,
- aeration time 8 - 24 hours (dependent on reaction rates for specific wastes),
- depth 4.5 metres,
- return sludge 25 - 100% of plant inflow rate,
- clarifier overflow rate 16 m³/day/m².

5.4 Effluent Polishing

5.4.1 Land disposal of wastewater

The application of wastewater to land is a low capital and operating cost method for the treatment of fruit and vegetable wastes, provided sufficient land having suitable characteristics is available. The ultimate disposal of wastewater applied to land is by one of the following methods:

- percolation to groundwater,
- overland runoff to surface streams,
- evaporation and evapotranspiration to the atmosphere.

The following methods are used for land application:

- irrigation,
- surface ponding,
- groundwater recharge by injection wells,
- subsurface percolation.

Although each of these methods may be used in particular circumstances for specific fruit and vegetable waste streams, irrigation methods are used the most frequently. Irrigation processes can be further divided into four sub-categories according to the rates of application and ultimate disposal of liquid as shown in Table 59 [17].

Approximately 50% of the fruit and vegetable plants in the United States utilize some form of land application; the majority of these systems use high rate spray irrigation procedures. Overland flow is suitable for wastewaters containing high concentrations of suspended solids and organics. This method is used as a roughing process to remove the solids and a portion of the BOD_5 , and the liquid is collected and treated further by biological processes prior to discharge.

Irrigation is a treatment process which consists of a number of segments:

1. Aerobic bacterial degradation of the deposited suspended material and evaporation of water and concentration of soluble salts.
2. Filtration of small particles through the soil cover, and biological degradation of entrapped organics in the soil by aerobic and anaerobic bacteria.

TABLE 59. LAND TREATMENT AND DISPOSAL PROCESSES [17]

PROCESS	OBJECTIVE	SUITABLE SOILS	DISPERSAL OF APPLIED WATER	IMPACT ON QUALITY OF APPLIED WATER
Overland flow	Maximize water treatment. Crop is incidental.	Slow permeability and/or high water table.	Most to surface runoff. Some to evapotranspiration and groundwater.	BOD ₅ and SS greatly reduced. Nutrients reduced by fixation and crop growth.
Irrigation	Maximize agricultural production.	Suitable for irrigated agriculture.	Most to evapotranspiration. Some to groundwater; little or no runoff.	BOD ₅ and SS removed. Most nutrients consumed in crop or fixed. Total dissolved solids greatly increased.
High Rate Irrigation	Maximize water treatment by evapotranspiration and percolation with crop production as a side benefit.	More permeable soils suitable for irrigated agriculture; may use marginal soils if coarse texture.	Evapotranspiration and groundwater; little or no runoff.	BOD ₅ and SS mostly removed. Nutrients reduced. Total Dissolved Solids substantially increased.
Infiltration-Percolation	Recharge water or filter water; crop may be grown with little or no benefit.	Highly permeable sands and gravels.	To groundwater; some evapotranspiration; no runoff.	BOD ₅ and SS reduced. Little change in total dissolved solids.

3. Adsorption of organics on soil particles and uptake of nitrogen and phosphorus by plants and soil microorganisms.
4. Uptake of liquid wastes and transpiration by plants.
5. Percolation of water to groundwater.

The importance of these processes depends on the rate of application of wastes, the characteristics of the waste, the characteristics of the soil and substrata, and the type of cover crop grown on the land.

5.4.1.1 Methods of application. Wastewaters can be applied by one of several methods:

1. Flood the surface periodically.
2. Distribute the wastewater through small channels.
3. Spray the wastewater, using fixed or movable rotary sprayers.
4. Drip irrigate through fixed or movable pipelines.

5.4.1.2 Equipment requirements. Equipment required for spray irrigation is relatively simple. Pretreatment steps include screening to separate coarse solids, removal of silt by sedimentation in equalization basins, and pH control between 6.4 - 8.4 to ensure the accessibility of nutrients to plants. Effluent storage should permit pumpage at constant rates. In northern areas, sufficient storage (generally facultative lagoons) should be provided to store the wastes during the winter period when the ground is frozen and spraying is impractical.

Centrifugal pumps designed to provide sufficient dynamic head to overcome suction, friction, static and pressure head losses, are generally used for irrigation applications. Sprinklers are generally set in aluminum or plastic distribution piping, either fixed in position or movable. Drainage tiles are sometimes installed below the spray field or on the down slope to catch excess runoff. Drainage systems are particularly important in those roughing treatment systems which are followed by additional biological treatment.

5.4.1.3 Preliminary investigations. Prior to the installation of an irrigation waste disposal system, the following information is required on alternative sites:

1. Physical Data:

- site preparation
- ease of access
- total area available
- slope of land (less than 15%)
- distance from waste source.

2. Climatology:

- wind direction and velocity
- precipitation
- temperature
- evaporation rates
- quantity of incident solar radiation.

3. Soils Information:

- type and depth
- chemical characteristics such as salinity, permeability and infiltration capacity; capacity to filter out suspended solids, to remove and oxidize organics, and to remove plant nutrients
- agricultural potential.

4. Substrata Information:

- depth to water table (greater than 1.5 m)
- types and characteristics of the substrata
- groundwater recharge
- permeability.

5. Agricultural Information:

- type of crop cover which can be grown
- potential crop yield under various application rates
- evapotranspiration rates
- nutrient assimilation capacity
- effects of pH, salinity.

Additional information should be obtained from soil and substrata corings to a depth of 3 to 5 metres. Percolation tests should be carried out to determine soil permeabilities and laboratory tests performed on soil

columns to determine a number of parameters. These include filtration rates, application rates to maintain aerobic soil conditions, capacity of the soil to degrade organic materials, and the potential for soil clogging.

5.4.1.4 Loading rates. The application rates should be determined by pilot plant testing for each particular location. The rate will depend on whether irrigation techniques are to be used for roughing treatment or as an ultimate disposal method.

There are both hydraulic and organic loading constraints on the use of this method for the ultimate disposal of effluent. If the maximum recommended hydraulic loadings are exceeded, the surface runoff would increase. Should the specified organic loadings be exceeded, anaerobic conditions could develop with resulting decrease in BOD_5 removal and the development of odour problems. Hydraulic loading rates, less evapotranspiration rates for different soil types are given in Table 60 for ideal conditions.

Normal loadings for irrigation are in the range given in Table 61. Applied loadings of organic suspended solids average approximately 8 g/m^2 but loadings up to 22 g/m^2 have been applied successfully. A resting period between applications is important to ensure survival of the aerobic bacteria. The spray field is usually laid out in sections such that resting periods of 4 - 10 days can be achieved.

5.4.1.5 Cover crop. The type of cover crop utilized is very important; it has been estimated that a good cover crop can increase the absorption capacity by 80 - 90% relative to uncovered ground. Dense vegetation increases soil erosion; in addition, growth of microorganisms is enhanced. Cover vegetation may be local grasses, vegetable crops, shrubs and trees. Alfalfa is in common use because of its resale value as a protein source, and wastewater irrigation in many instances doubles the yield of this crop.

Typical organic and hydraulic application rates for specific commodities are given in Table 62. These values apply to specific effluents from certain fruit and vegetable processing operations. Inspection of Table 62 shows that the application rate varies from 2.5 g/day/m^2 for asparagus and beans to 134 g/day/m^2 for peas.

5.4.2 Effluent filtration

Effluent filtration may be applied in those instances where the levels of suspended solids in the effluent from biological treatment are

TABLE 60. IRRIGATION OF WASTEWATER - RECOMMENDED MAXIMUM LOADINGS [17]

SOIL TYPE	MOVEMENT THROUGH ROOT ZONE	
	(m/day)	(m/year)
Fine Sandy	0.38	7.6
Sandy Loam	0.19	4.6
Silty Loam	0.08	2.3
Clay Loam	0.038	1.0
Clay	0.013	0.25

TABLE 61. IRRIGATION OF WASTEWATER - RECOMMENDED BOD_5 LOADING RATES [1]

	$g/hr/m^2$	$g/day/m^2$
Fallow soil; no fresh organics	0.11 - 0.22	4.03
Fallow soil following addition of organic residues	0.22 - 0.45	8.06
Soil with growing plant	0.34 - 0.67	12.1
Maximum for well aerated soils	-	11.2

TABLE 62. IRRIGATION OF FOOD PROCESSING WASTES - TYPICAL LOADING RATES [1]

COMMODITY	BOD ₅ APPLIED (g/day/m ²)	HYDRAULIC LOADING (m/day)
Asparagus, Beans	2.5	0.089
Cherries	90.8	0.092
Corn	96.2	0.087
Lima Beans	7.3	0.009
Peas	134	0.04
Tomatoes	45.8	0.076
Tomatoes	17.9	0.018

outside prescribed limits. The suspended material is often colloidal and may not readily settle out in a final clarifier. Following discharge to a receiving stream, these solids tend to settle out and decompose in quiescent areas of the stream.

Effluent filtration may be achieved by one of the following methods:

- slow sand filters,
- rapid sand filters,
- reverse bed multi-media filters.

5.4.2.1 Slow sand filtration. Wastewater is applied on an intermittent basis to a bed of sand having a uniformity coefficient of 0.36 to 0.66 mm and a bed depth of 0.6 m. The sand is laid on a gravel bed on top of an underdrain tile bed. Application rates of $0.12 \text{ m}^3/\text{hr}/\text{m}^2$ have resulted in 60% removal of the suspended solid material. BOD_5 may be reduced by 40% through the removal of the suspended solids, but bacteriological degradation of soluble organics also occurs in the top few centimetres of the bed where a biological growth develops.

The filters are operated for one day and taken out of service for several days. Over a period of time, the bacterial growth increases and filtration rates decrease significantly. The filter beds are then raked and the top few centimetres of sand replaced approximately every 60 days. Another drawback of the slow sand filter is that a relatively large area is required for filtration; in addition, operation during winter months is impractical.

5.4.2.2 Rapid sand filtration. Higher application rates ($2.4 - 20 \text{ m}^3/\text{hr}/\text{m}^2$) may be achieved by using single sand medium or multi-media filter beds equipped with facilities for backwashing and surface washing. Filter beds 30 - 60 cm deep can remove up to 70% of the applied suspended solids material at rates of $5 - 15 \text{ m}^3/\text{hr}/\text{m}^2$. The sand has an effective size of 0.7 mm and a uniformity coefficient of 1.62. The use of alum, ferric chloride, coagulant aids and polymers can improve the suspended solids and BOD_5 removal efficiencies.

Frequent backwashing at $36 \text{ m}^3/\text{hr}/\text{m}^2$ and at a minimum frequency of every 24 hours are required to prevent clogging and reduction in filtration

rates. During backwashing, the sand grades hydraulically with the finest particles settling at the top of the bed. Thus most of the filtration occurs in the top few centimetres of sand, the remainder of the voids being unavailable for particulate removal.

An increase in the effective filter depth can be achieved by utilizing materials of different specific gravities such that the size of the materials decrease from coarse to fine with increasing depth. Sand, anthracite and garnet have been used successfully; effective sizes and specific gravities are given in Table 63.

5.4.2.3 Reverse bed multi-media filtration. Mixed media filtration provides longer filter runs and improved system reliability. The effluent from activated sludge treatment systems containing suspended solids at the 100 mg/l level can be successfully treated to produce an effluent containing 3 - 10 mg/l at filter runs of 15 - 24 hours at a loading rate of $12 \text{ m}^3/\text{hr}/\text{m}^2$. The removal efficiency depends on the degree of flocculation provided by the biological treatment process. Flocculation can be increased by the addition of coagulants and polymers at the final clarifiers in the activated sludge process.

Few data are available on the efficiency of effluent filtration in improving the quality of fruit and vegetable plant wastewater. Table 64 gives an indication of anticipated improvements in BOD_5 and suspended solids concentrations by the use of effluent filtration.

5.5 Solid Waste Treatment and Disposal

5.5.1 In-plant processing wastes

The solid waste generated in the fruit and vegetable processing industry results principally from in-plant processes, ranging from 8% for tomato processing to 66% for corn on a total raw product basis [3]. In the case of corn processing wastes, the major part of the solid material is produced in a dry form and may therefore be collected and utilized as animal feed. The majority of wastes generated in other fruit and vegetable processing operations cannot be stored for long periods without decomposing and therefore they have only limited use as by-products.

Inspection of Table 65, giving by-product usage, shows that 62% of the 66% solid waste in corn processing is utilized as a by-product. In

TABLE 63. FILTER MEDIA - EFFECTIVE SIZE AND SPECIFIC GRAVITY

MEDIUM	EFFECTIVE SIZE mm	SPECIFIC GRAVITY	DEPTH cm
Sand	0.4 - 1.0	2.6	20
Anthracite	0.8 - 2.0	1.6	60
Garnet	0.4 - 0.8	4.2	8

TABLE 64. MULTI-MEDIA, RAPID SAND FILTRATION - GRAPE PROCESSING WASTES [1]

	BOD ₅ (mg/l) AVERAGE	MAXIMUM DAY	SS (mg/l) AVERAGE	MAXIMUM DAY
Raw Waste	4096	--		
Activated Sludge Effluent	21	114	28	216
Filtered Effluent	8	32	8	20

TABLE 65. IN-PLANT SOLID WASTE DISPOSAL - FRUIT AND VEGETABLE WASTES [17]

PRODUCT	TOTAL SOLID WASTE *	% BY-PRODUCT	% SOLID WASTE
Apples	28	19	9
Green Beans	21	10	11
Beets, carrots	41	21	20
Corn	66	62	4
Olives	14	12	2
Peaches	27	9	18
Peas	29	9	20
Peas	12	8	4
Tomatoes	8	2	6
Vegetables (misc.)	22	9	13

* Expressed as % raw material.

contrast, only 9% of the 29% solid waste from pear processing is utilized as a by-product, the remaining 20% being handled as a normal solid waste.

Although the solid waste material obtained from most commodity processing has potential utilization as an animal feed, there are a number of factors which limit its use:

1. High moisture content.
2. Rapid decomposition.
3. Short processing season.
4. Incompatibility with other feed components.
5. Distance of food processor from market.
6. Low nutrient value in comparison with other feeds.
7. High reprocessing cost.

Research is being carried out to maximize the use of food processing wastes, particularly in moisture removal and in improvements in storage methods.

Typically, the in-plant solid wastes are collected and hauled daily to land disposal sites. Depending on the unit process and the commodity being processed, it may be necessary to dewater the collected solids prior to landfill in order to minimize ground and surface water pollution.

5.5.2 Waste treatment plant solids disposal

The high BOD_5 and suspended solids concentrations of the fruit and vegetable wastes result in the generation of large volumes of solid wastes and sludge in excess of quantities generated by equivalent operations in municipal treatment plants. Solid wastes are generated from screening, primary treatment, and secondary treatment. The quantities of solids expected depend on initial concentrations of suspended solids and BOD_5 , the design criteria applicable to the removal processes and the specific commodity processed. It should be pointed out that small scale or pilot scale testing of specific commodity waste is required to obtain accurate data. Similarly, the density and biodegradability of the solids will be a function of the treatment process and the nature of the raw waste material.

The screened solids may be dewatered and disposed of by utilizing the following steps:

- dewatering,
- digestion,
- disposal.

5.5.2.1 Dewatering techniques. Sludges obtained from waste treatment processes contain 70 - 99.5% moisture. Dewatering prior to ultimate disposal is required in order to reduce the quantity of material to be handled in the treatment, transportation and disposal of the sludge.

The moisture content of the sludge is generally first reduced in a gravity or flotation thickener. Compaction of sludge solids can be accelerated in a specially designed gravity settler by agitating the sludge. The solid concentration can be increased to approximately 10%, using either gravity or flotation thickeners.

Sludges can be dewatered to 25% solids concentration by the use of centrifuges. The sludges can be pre-thickened, pre-conditioned with a coagulant or fed directly to continuous centrifuges. Centrifuges do not produce as dry a product as vacuum filters but are cheaper and easier to operate. In addition, they may also be operated using sludges having high moisture contents.

The rotary continuous vacuum filter is a suitable method for sludge dewatering, provided the unit is properly designed and the operation carefully controlled at optimum conditions.

Pressure filters are not normally used in waste treatment applications because of cost and operational difficulties. The rate of sludge dewatering is approximately $10 - 50 \text{ kg/hr/m}^2$ on a dry sludge basis.

Sludge drying beds may be used to dewater digested sludge. The drying beds have a sand base and an underdrain system to collect water which percolates through the sludge. Drained water is returned to the wastewater treatment plant. When the sludge is sufficiently dry, it is removed.

5.5.2.2 Digestion. Both anaerobic and aerobic digestion may be used for the treatment of biological sludge. Anaerobic digestion is used in municipal treatment plants. The digesters must be covered and the methane produced handled either as a fuel or burned. An anaerobic digester will reduce the organic fraction in the sludge by 50 - 60% at a detention time of approximately 20 days at 32°C . In general, this method is used to digest fruit and vegetable industry wastewater treatment sludges in combination with domestic sludge.

Aerobic digestion is not as efficient as anaerobic digestion and reduces the volatile content of the sludge by approximately 40% at a detention

time of 15 - 20 days. Sufficient air is supplied to the open digester to satisfy the oxygen requirements of the microorganisms.

5.5.2.3 Disposal. Dewatered and digested sludge is generally disposed of in a landfill operation. There may be a number of problems associated with this method of disposal including insects, rodents and odours.

The waste sludge is generally applied to the land either as a fertilizer or as disposal. The objective of its use as a fertilizer is to maximize crop production in addition to utilizing the waste sludge as a nutrient source and as a soil conditioner. The loading rates are of the order of $0.1 - 0.4 \text{ kg/m}^2/\text{yr}$, on a dry solids basis. In contrast, the objective of the disposal method is to maximize sludge disposal by incorporating large quantities of the solid into the soil. Loading rates in this instance are in order of 5 - 45 t/yr. The sludge should be dewatered prior to land application and the pH should be adjusted to 6.4 - 8.4.

5.6 Summary Of Commodity Specific Treatment Technology

It is apparent from the discussion of wastewater treatment methods that the liquid wastes from the fruit and vegetable processing industry are readily biodegradable. Based on recent published information and on that made available through Environmental Associates, Inc., the most common methods of waste treatment, other than pretreatment and discharge to municipal waste treatment systems, are the following:

1. Holding lagoons with seasonal discharge.
2. Aerated lagoon systems.
3. Activated sludge.
4. Spray irrigation.

Combinations of these various processes are utilized in many cases. Data on specific food processing wastes are summarized in Table 66. It should be emphasized that only those commodities common to the Canadian industry and discussed in detail in Section 3 of this report have been included in this table.

A number of conclusions can be reached from inspection of Table 66:

1. The wastes are readily biodegradable, with most secondary treatment processes achieving at least 90% removal of BOD_5 .

TABLE 66. SCREENED WASTEWATER AND FINAL EFFLUENT DATA FOR VARIOUS COMMODITIES

COMMODITY PLANT WASTE TREATMENT SYSTEM	APPLE PRODUCTS		PEACHES		STRAWBERRIES	
	ACTIVATED SLUDGE		1 ACTIVATED SLUDGE	2 SETTLING	AERATED LAGOON & SETTLING POND	
Screened Wastes						
BOD ₅						
(mg/l)	1440		833	3900	176	
(kg/t)	10.2		35.0	13.3	5.1	
SS						
(mg/l)	60		--	1140	123	
(kg/t)	0.75		--	3.9	3.7	
Final Effluent						
BOD ₅						
(mg/l)	--		10.3	1200	6.2	
(kg/t)	--		0.43	4.6	0.14	
SS						
(mg/l)	--		--	2010	7.0	
(kg/t)	0.039		--	7.6	0.16	
Removal (%)						
BOD ₅	--		98.5	69.2	96.5	
SS	64.5		--	--	94.3	

TABLE 66. (Continued)

COMMODITY PLANT	1	CORN 2 SERIES AERATED LAGOONS	3	1	PEAS 2 AERATED LAGOON AND SPRAY IRRIGATION	3 SPRAY IRRIGATION AND AERATED LAGOONS
WASTE TREATMENT SYSTEM	SPRAY IRRIGATION		FILL/DRAW LAGOONS	ACTIVATED SLUDGE		
Screened Wastes BOD ₅						
(mg/l)	--	--	--	1900	--	--
(kg/t)	24.3	3.3	9.3	48.5	23.7	6.5
SS						
(mg/l)	--	--	--	318	--	--
(kg/t)	8.4	8.6	1.5	8.1	27.2	10.3
Final Effluent BOD ₅						
(mg/l)	--	--	171	12	--	--
(kg/t)	0.6	0.4	3.5	0.3	0.9	1.3
SS						
(mg/l)	--	--	9.2	15	--	--
(kg/t)	0.7	0.8	0.2	0.4	0.6	0.8
Removal (%)						
BOD ₅	97.5	86.9	62.3	99.4	96.3	97.9
SS	88.1	91.1	86.7	95.3	80.6	92.3

TABLE 66. (Continued)

COMMODITY PLANT	SNAP BEANS		LIMA BEANS	
	1 AERATED LAGOON, CLARIFICATION & SAND FILTRATION	2 SERIES LAGOONS	1 AERATED LAGOON AND SPRAY IRRIGATION	2 SPRAY IRRIGATION AND AERATED LAGOONS
WASTE TREATMENT SYSTEM				
Screened Wastes				
BOD ₅				
(mg/l)	1190	165	--	--
(kg/t)	19.9	149	105	30.6
SS				
(mg/l)	666	15	--	--
(kg/t)	11.1	13.5	43.7	61.0
Final Effluent				
BOD ₅				
(mg/l)	170	14	--	--
(kg/t)	3	12.2	7.5	11.6
SS				
(mg/l)	91	11	--	--
(kg/t)	1.5	9.9	6.5	6.4
Removal (%)				
BOD ₅	85.7	91.7	92.9	78.7
SS	86.3	26.2	73.5	89.5

TABLE 66. (Continued)

COMMODITY WASTE TREATMENT SYSTEM	CARROTS HOLDING POND	TOMATOES AERATED LAGOONS	SAUERKRAUT HOLDING POND
Screened Wastes			
BOD ₅			
(mg/l)	2190	1000	1500
(kg/t)	--	2.3	34.8
SS			
(mg/l)	274	691	1370
(kg/t)	--	1.6	32.2
Final Effluent			
BOD ₅			
(mg/l)	210	13	84
(kg/t)	--	0.028	0.82
SS			
(mg/l)	310	44	38
(kg/t)	--	0.09	0.37
Removal (%)			
BOD ₅	90.4	98.6	94.4
SS	--	93.6	97.2

2. The treatability of the wastes appears to be independent of the commodity processed.
3. Final effluent loadings are generally in the range of 0.2 - 5 kg BOD₅/t and 0.1 - 0.8 kg SS/t on a raw product basis.

These data and those presented earlier in this section are used as a basis for the assessment of the waste treatment systems used in the Canadian plants taking part in the plant survey and discussed in Section 7 of this report.

6

GENERAL TREATMENT COST INFORMATION

The purpose of this section is to provide a brief general discussion of the variables which affect cost and to present order-of-magnitude costs associated with the provision of waste treatment at fruit and vegetable processing facilities. It is not intended to be a complete guide to treatment costs since this is outside the scope of this study. The major variables affecting pollution abatement costs for a given fruit and vegetable processing plant are as follows:

1. Commodity or commodities being processed and associated production rates.
2. Treatment technology in place.
3. Plant location.

The commodity or commodities being processed and the associated production rates determine to a great extent the hydraulic and pollutant loadings, and the time duration and variability of the loads. These factors in turn determine to a certain extent the applicability of the available treatment methods which may be used. In addition, the commodities being processed determine the production operations used within the plant and influence the type of in-plant abatement modifications which can be utilized.

The waste treatment facilities or processing technology already in-place may influence significantly the costs of achieving effluent limits set by regulatory authorities. In some instances, the pollution control facilities may be achieving a final effluent quality within specified limits. Conversely, the existing abatement technology may require upgrading in order to meet pollution control regulations.

Plant location plays a very important role with respect to abatement technology and associated costs. The availability and accessibility of land in the region of the processing plant greatly influences the waste treatment and disposal options available to the plant, space limitations being the major constraining factor. Other location related factors include climate, construction costs, labor availability and costs, and energy costs.

The location can also influence greatly the given plant's abatement costs in terms of proximity to a municipal waste treatment facility. Should the municipal system have sufficient capacity to handle adequately the plant

effluent, the associated user charges may be lower than those incurred through the operation of an internally owned facility. In some cases, primary treatment facilities may be required to achieve a quality acceptable to the municipality controlling the installation. Nevertheless, the capability of discharging to a municipally owned treatment facility should be carefully evaluated as an abatement option.

The above discussion implies that the costs involved in installing and operating pollution abatement facilities are very site/plant specific. Cost information provided in most literature sources is qualified by various assumptions and must be carefully evaluated prior to application to given plant criteria. However, the data are valuable in that they provide comparative order of magnitude capital and operating costs associated with various treatment alternatives.

Table 67 summarizes a number of secondary treatment processes and gives a relative comparison of some pertinent characteristics or criteria associated with each process. In spite of being quite general, this summary provides a reference frame of the advantages and disadvantages of alternative abatement processes.

In order to provide some indication of the relative capital and operating costs associated with a number of treatment technologies, reference has been made to a recent publication by the United States Environmental Protection Agency [17]. In this publication cost estimates for various abatement options were developed on the basis of the following criteria:

Flow	3785 m ³ /day (Average)
	7570 m ³ /day (Peak)
BOD ₅	1000 mg/l
SS	1000 mg/l
pH	4.5
Season	90 days
Amortization	10 years at 12%
Engineering, Legal and Contingency costs included at 25% of construction costs.	
October, 1975 dollars (United States dollars and basis).	

Table 68 summarizes the costs, and the assumptions made for a number of treatment systems [17].

TABLE 67. TREATMENT PROCESS COMPARISONS [17]

PROCESS	CAPITAL COST (NO LAND)	OPERATING & MAINTENANCE COST	AREA/LAND REQUIREMENT	ENERGY REQUIREMENT	STABILITY	LEVEL OF OPERATOR SKILL REQUIRED	REMOVAL EFFICIENCY
Stabilization Ponds	1	1	4	1	1	1	1
Aerated Lagoons	1	1	3	2	1	1	2
Air Activated Sludge	3	3	2	3	2	3	4
Oxygen Activated Sludge	4	4	1	4	4	4	5
Rotating Biological Contactors	3	2	2	2	3	2	4
Trickling Filters	2	2	2	2	2	2	3

Ratings: 1 = lowest, etc.

TABLE 68. ABATEMENT/TREATMENT TECHNOLOGIES - COST SUMMARY [17]

PROCESS	ASSUMPTION*	CAPITAL	COST SUMMARY		UNIT COST (CENTS/m ³)
			ANNUAL OPERATING & MAINTENANCE (U.S. DOLLARS)	AMORTIZED CAPITAL COST (U.S. DOLLARS)	
Screening and Flow Measurement	- 20 mesh tangential screen - solids hauling & disposal @ \$4.00 per cubic yard	71,600	3,200	12,700	4.7
Neutralization	- 2 tanks in series with 15 minutes average retention - neutralization with 20% NaOH @ 200 mg/l NaOH - NaOH cost at \$165 per anhydrous ton - tank truck shipping cost at 3¢/100 lb liquid/mile with 100 mile haul	100,000	23,600	17,700	12.1
Aerated Lagoon System	- both aerated lagoon and and settling pond earth lined - depth 10 feet, inside side slope 3:1, outside 2:1 - 30 day detention in lagoon - 400 USGPD/SF overflow rate in settling pond - no nutrient addition - excavation cost \$4/cubic yard	1,160,000	16,000	205,300	67.1

TABLE 68. (Continued)

PROCESS	ASSUMPTION*	COST SUMMARY			UNIT COST (CENTS/m ³)
		CAPITAL	ANNUAL OPERATING & MAINTENANCE (U.S. DOLLARS)	AMORTIZED CAPITAL COST	
Activated Sludge System	- power cost 2¢/KWH				
	- mechanical aerators: 12 @ 40 HP each and 1 @ 20 HP				
Activated Sludge System	- earthen lined aeration basin with 2-day detention				
	- two conventional clarifiers with 400 GPD/SF overflow rate	65,000	175,000	114,150	84.8
Activated Sludge System With Aerobic Digestion and Dewatering	- cost of NaOH @ \$184/TON (100% basis); cost of H ₃ PO ₄ @ \$.215/lb solution				
	- power cost @ 2¢/KWH				
Activated Sludge System With Aerobic Digestion and Dewatering	- sludge disposal cost @ 1.5¢/gal for 20 mile haul				
	- same assumption as for activated sludge system given above	1,115,000	58,500	197,350	75.0
Activated Sludge System With Aerobic Digestion and Dewatering	- dewatered sludge disposal @ \$.70/TON dry solids/mile				
	- polymer addition @ 6 lb/TON solids				
Activated Sludge System With Aerobic Digestion and Dewatering	- polymer cost @ \$.25/lb				
	- unit dewatering rate @ 100 GPH for digested sludge				

(* approximately \$130,000 of this total contributable
to sludge hauling and disposal)

TABLE 68. (Continued)

PROCESS	ASSUMPTION*	COST SUMMARY				UNIT COST (CENTS/m ³)
		CAPITAL	ANNUAL OPERATING & MAINTENANCE (U.S. DOLLARS)	AMORTIZED CAPITAL COST		
Land Application	- excluding land costs					
a. Spray irrigation	- 124 acres required	415,000	43,600	73,600	34.4	
b. Overland flow	- 77 acres required	390,600	34,400	64,100	30.4	
c. Infiltration - Percolation	- 5 acres required	218,900	15,800	38,700	16.0	
Filtration	- 150,000 gallon earthen surge pond ahead of filters	271,000	4,000	47,960	15.2	
	- 60,000 gallon clearwell					
	- 60,000 gallon backwash return surge pond					
	- polymer dose 1 mg/l					
	- two pressure ₂ filters with 2.5 USGPM/Ft ² application rate					
	- 18 GPM/Ft ² backwash rate					
Chlorination System	- concrete chamber with 1 hour detention at average flow	38,000	2,800	6,725	2.8	
	- chlorine dosage 1 mg/l					
	- chlorine cost 27.5¢/pound					
	- small building included					

* English units retained for convenience.

A number of conclusions can be drawn from Table 68:

1. Although the capital cost for the activated sludge system utilizing liquid sludge disposal is much less than that for the system incorporating dewatering technology, the unit cost of treatment for the higher capital system is substantially lower. The lower unit cost is attributable to lower operating and maintenance costs. Thus there is the need for not only estimating the capital costs of the systems but of also assessing the ongoing operating costs.
2. It should be noted that land cost has not been included in the estimates given in Table 68. At present day values of land, the inclusion of this cost could increase associated unit costs substantially.
3. The cost summary provided for the filtration process (a tertiary or advanced waste treatment method) is based on the treatment of secondary effluent. Thus the unit cost of this method would be added to the unit costs of the secondary process being used in order to obtain a total unit cost for treatment.
4. If disinfection of plant wastewater were required, chlorination facilities would represent a cost in addition to that associated with secondary treatment.

In conclusion, it must be re-emphasized that no two fruit and vegetable processing plants are identical. Their operations are affected by many variables which in turn affect the quality and quantity of the wastewaters produced. The variations in the wastewater characteristics in turn affect the type, size, and operating conditions of applicable abatement and treatment technologies. All these factors lead to the conclusion that the capital and operating costs associated with the treatment of wastewaters originating from the fruit and vegetable processing industry must be carefully analyzed and assessed, in light of the characteristics and individuality of each processing plant.

7 CANADIAN FRUIT AND VEGETABLE PROCESSING INDUSTRY

7.1 Introduction

This section discusses in detail the wastewater related information obtained during the surveys carried out at Canadian processing plants. Particular consideration has been given to in-plant screened and treated wastewater characteristics. In addition, the topics of wastewater toxicity and bioassay testing are discussed in depth.

However, before discussing the plant survey information, a brief statistical review of the quantities of major fruits and vegetables being processed in Canada is given. The purpose of this review is to indicate the size of the Canadian processing industry and the major commodities being processed.

7.2 Statistical Review

The Canadian fruit and vegetable processing industry is a multi-million dollar manufacturing activity. The value of shipments of manufactured goods in 1972 totalled approximately 631 million dollars. Three provinces, British Columbia, Ontario and Quebec, are the major processing areas contributing 9%, 62%, and 15% of the total value of shipments, respectively.

The manufacturing process descriptions included within this report relate to specific commodities which were considered to reflect the major fruits and vegetables being processed in Canada. The list of commodities, covered in this report, was obtained from an assessment carried out on production data published by Statistics Canada. Table 69 summarizes the total pounds of specific fruits canned in Canada for the years 1971, 1972, 1973 and 1974. Table 70 summarizes similar data for canned vegetables; information specific to frozen products was not available. Table 71 provides additional information on other commodity products that are a major portion of the Canadian industry.

The total pack of processed fruit in 1973 was in the order of 121 million pounds. Apples and apple sauce, peaches, pears, apricots, cherries, and plums constituted approximately 86% of this total poundage. In the case of vegetables, the 1973 total production was approximately 642 million pounds, of which 84% consisted of beans, corn, peas, beets, carrots, and tomatoes.

TABLE 69. PRODUCTION OF CANNED FRUITS IN CANADA

COMMODITY	1971	YEAR		1974
		1972	1973 (metric tonnes)	
Apples, Apple Sauce (including crab apples)	17800	20000	18000	--
Pears	14000	13400	13900	12900
Peaches	8080	9210	7730	7650
Cherries (sweet & sour)	3300	3440	4500*	6010*
Plums	1930	2330	2880	2260
Strawberries	1440	1420	710*	970*
Apricots	1250	1060	620	860
Raspberries	580	640	540	610
Blueberries	440	330	--	--

* Some data not reported.

Source: Statistics Canada, Fruit and Vegetable Processing Industries.

TABLE 70. PRODUCTION OF CANNED VEGETABLES IN CANADA

COMMODITY	1971	YEAR		1974
		1972	1973	
		(metric tonnes)		
Beans - green wax	35300	35900	40300	40300
- lima	1150	920		
- baked with pork	53900	51600	57400	55200
Corn (Cream, whole grain)	49500	50800	50500	46700
Peas	46900	44400	43100	52600
Tomatoes	26200	23100	39000	32800
Beets	11600	10500	8000	9550
Carrots	8210	4930	6550	5830
Asparagus	5310	6000	5450	5880
Carrots & Peas	4570	4460	4320	4380
Corn on Cob	3610	2870	5250	4020
Pumpkin & Squash	2920	3100	2930	2180
Mushrooms	2570	2910	9520	8240

Source: Statistics Canada, Fruit and Vegetable Processing Industries.

TABLE 71. PRODUCTION OF OTHER FRUIT AND VEGETABLE COMMODITIES IN CANADA

COMMODITY	1971	YEAR		1974
		1972	1973	
		(metric tonnes)		
Tomato - Juice	80700	82200	96200	77000
- Catsup (Ketchup)	35400	44000	48200	50200
- Pulp, Paste, & Puree	1930	--	9920	--
Apple - Juice	83700	81400	50800	--
- Piefilling	4000	4150	3650	3810
Jams	24700	20900	32200	34400
Jellies	1770	1690	4060	4160
Pickles	44200	45900	--	--
Relishes	7850	8600	--	--

Source: Statistics Canada, Fruit and Vegetable Processing Industries.

7.3 Wastewater Characteristics

7.3.1 Introduction

It was pointed out in Section 2 of this report that the prime sources of data on the Canadian industry were those eight plants at which information collection and wastewater sampling programs were carried out. The intent of the surveys was to obtain analytical data on the individual plant's wastewater by means of a sampling and analysis program, supplemented by information on the unit processes, wastewater treatment systems and other relevant data to be supplied by the individual plants. The program attempted to cover the following aspects:

1. Physical Plant Data:
 - raw materials processed and relative proportions,
 - final products,
 - production capacity,
 - process water flow, or flows if varied for different raw materials.
2. Wastewater Characteristics and Loadings:
 - wastewater flows and characteristics related to unit processes, total untreated effluent, and final treated effluent, and specific commodities whenever possible,
 - identification of waterborn pollutants.
3. In-plant control techniques and technologies,
4. Wastewater Treatment Facilities:
 - type, capacity, operations, etc.
 - efficiency of removal.

It was not possible during the course of the five-day surveys conducted at each plant to obtain all the information initially envisaged. In some cases, the requested information was not recorded by the plants, considered confidential and not to be released, or was to be provided in the inventory questionnaire to be circulated by Environment Canada. At some plants, data and information were obtained only on the treated wastewater and the treatment facilities, since survey personnel were not permitted to enter the processing areas.

A major area of difficulty encountered during the survey was that of measuring in-plant unit process wastewater flows. Physical constraints (numerous discharge points, common collection gutters, underground collection systems, etc.) and economic/time constraints precluded extensive attempts to obtain flow data. It was considered that the unit flow data which were obtained were not of sufficient accuracy to develop unit waste loadings. For this reason, the impact of specific unit operations, presented later in this section, has been assessed on the basis of BOD_5 concentrations.

Total wastewater flows (treated and untreated) were being measured and recorded by the plants. These flow data were recorded during the surveys, and raw and final wastewater loadings developed.

The in-plant unit process wastewater characteristics and raw wastewater loadings developed from plant survey data are compared in this section with those data developed in Section 3. The types of wastewater treatment facilities utilized by the plants surveyed, and the respective efficiencies and final effluent quality are compared with data developed in Section 5; the data presented in Section 5 is based on the fruit and vegetable industry in the United States. The subject of toxicity of the total effluents from the study plants is discussed under "Wastewater Treatment" later in this section.

It should be noted that, in order to maintain confidentiality of information on any given Canadian operation, no specific reference is made to plant name or location. During the following discussions of specific commodities, a numbering sequence is used in referring to given Canadian plants. This sequence is not maintained between commodities, being varied to ensure further the anonymity of the companies taking part in the survey.

7.3.2 In-plant wastewater characteristics

The concentrations of BOD_5 and suspended solids in the in-plant wastewater streams at the survey plants are compared by commodity and, where possible, with data developed from the United States industry. The last column of figures in Tables 72 through 82 in this section present the United States data and references the table in this report or specific documents from which information was obtained.

7.3.2.1 Apple products. A comparison of BOD_5 and suspended solids concentrations for specific in-process streams for apple sauce and apple slice

processes is given in Table 72. Inspection of the data on the sauce operation shows significant concentrations arise from the peeling and coring operations, and the can wash. The high loading from the peeling/coring operation is expected, while the high concentration from the can washing operation is due to sauce spillages during the filling operation. In the case of slicing and deaeration, the BOD_5 and suspended solids concentrations from the Canadian operation (Plant 2) compare favourably with the U.S. analytical data. The BOD_5 concentration originating from cooking apple slices for Plant 2 is also comparable with American data. The difference in suspended solids value cannot be adequately explained since details of the operations of the United States plant are not known.

Generally, the concentration values in Table 72 support the unit operation contributions to the total pollutant load detailed in Table 3.

7.3.2.2 Plums. Analytical data on wash water streams for a Canadian plum operation are given in Table 73. Since similar or related unit operations data on U.S. plum processors were not available, the only general point to be made is that the effluent contributions of the two wash streams are small in comparison to known total effluent values.

Referring to Table 14, plum wash water streams contribute approximately 15% of the total BOD_5 and suspended solids loadings, the major loading (60%) originating from the pitting operation. The Canadian operation investigated did not incorporate pitting, canning only whole plums.

7.3.2.3 Corn. Table 74 indicates wastewater characteristics for a number of inplant processing streams for two Canadian corn processing operations. These data show relatively high concentrations in the waste streams from the husker washer and the kernel washer.

7.3.2.3 Beets. Data taken from a wash operation downstream from the beet peeling operation, for a specific beet processing operation in Canada, indicated a BOD_5 concentration of 430 mg/l. This figure is of the same order of magnitude as the average effluent loading indicated for the wash operation in the beet processing plant given in Table 29.

7.3.2.4 Tomatoes. The only in-plant analytical wastewater data obtained on the Canadian tomato processing operation referred to the initial washing and fluming of this commodity; the BOD_5 concentrations ranged from 460 to

TABLE 72. IN-PLANT WASTEWATER CHARACTERISTICS
APPLE SAUCE AND SLICES

WASTEWATER SOURCE	PLANT NO. PRODUCTION (t/day) (PRODUCT)	1 40 - 60 (SAUCE)	2 10 - 20 (SLICES)	TABLE 1 76.3 (SLICES)
Apple Wash	BOD ₅ (mg/l)	22 - 128		620
	SS (mg/l)	9 - 61		38
Peeling & Coring	BOD ₅ (mg/l)	5500 - 7100	7000	
Including Transport	SS (mg/l)	350 - 800	30	
Slicing and	BOD ₅ (mg/l)		7000	6600 *
Deaeration	SS (mg/l)		600	430 *
Spray Wash	BOD ₅ (mg/l)		2880	
	SS (mg/l)		276	
Cook	BOD ₅ (mg/l)		7000	10800
	SS (mg/l)		73	415
Can Wash	BOD ₅ (mg/l)	1100 - 4800		
	SS (mg/l)	70 - 480		
Can Cool	BOD ₅ (mg/l)	15 - 70		345 *
	SS (mg/l)	5 - 6		86 *

* Data taken from Reference [3] to supplement data from Table 1.

TABLE 73. IN-PLANT WASTEWATER CHARACTERISTICS - PLUMS

WASTEWATER SOURCE	PLANT NO. PRODUCTION (t/day)	1 30 - 40	TABLE 13 27.2 - 517
First Cold Wash	BOD ₅ (mg/l)	310	-
	SS (mg/l)	40	-
Second Cold	BOD ₅ (mg/l)	130	-
Wash	SS (mg/l)	20	-
Final Effluent	BOD ₅ (mg/l)	-	804 - 1430
	SS (mg/l)	-	40 - 163

TABLE 74. IN-PLANT WASTEWATER CHARACTERISTICS - CORN

WASTEWATER SOURCE	PLANT NO. PRODUCTION (t/day)	1 120 - 170	2 120 - 180	TABLE 19 35 t/hr
Wash	BOD ₅ (mg/l)	-	1800 - 2300	4000
(after husker)	SS (mg/l)	-	330 - 650	1650
Wash	BOD ₅ (mg/l)	-	-	3360
(after desilker)	SS (mg/l)	164	-	880
Kernel	BOD ₅ (mg/l)	7000	-	-
Wash	SS (mg/l)	2080	-	-

2100 mg/l and the suspended solids levels from 170 to 670 mg/l. These wide ranges of wastewater parameter concentrations for the same processing operation provide an excellent example of the variations in loadings which can be expected in the in-plant processing streams.

In this instance, the pollutant concentration variation is a function of the total quantity of tomatoes being processed and their quality. Damaged tomatoes and over-ripe tomatoes tend to split apart in the wash and flume water, adding greatly to the soluble BOD_5 content of this stream.

7.3.3 Screened wastewater characteristics

Analytical data and production data obtained from the Canadian plants taking part in this survey were developed and compared with data available from the United States fruit and vegetable industry. The U.S. data were presented in Section 3 as the log mean average, maximum and minimum values; it was pointed out in Section 3 that the maximum and minimum values quoted were not absolute but represented one standard deviation from the log mean values. These maximum and minimum values were used for comparing equivalent data in Canadian plants. The pH of the screened wastewater streams was compared with equivalent data taken from Table 50.

7.3.3.1 Apple products. Table 75 presents data on three Canadian plants and equivalent data on United States plants for the purposes of comparison, and pH data taken from Table 50. A number of conclusions can be drawn from inspection of this table:

1. Plant 1 is a large plant by North American standards whereas Plant 2 is small by North American standards.
2. The water consumption in m^3/t and BOD_5 loading in kg/t are small in Plant 1 compared with the United States range.
3. In contrast, the water consumption at the small Canadian plant (Plant 2) is high, ranging from 39 - 62 m^3/t compared with the United States industrial range of 1.8 - 27 m^3/t . The BOD_5 and SS loadings in Plant 2 are also correspondingly high compared with the United States data.

It should be pointed out that the range of BOD_5 loadings from Plant 1 (2.7 - 5.6 kg/t) agrees with the historical values for this parameter for this particular plant.

TABLE 75. PRODUCTION RATES AND SCREENED WASTEWATER DATA - APPLE PRODUCTS

PLANT NO.	1*	2*	3*	TABLE 2
Production (t/day)	170 - 310	11 - 20	-	3.82 - 114
Flow Volume (m ³ /day)	590 - 1090	570 - 1150	-	98.4 - 1980
Flow Ratio (m ³ /t)	2.1 - 6.3	39 - 62	-	1.77 - 27.0
BOD ₅ (mg/l)	875 - 1570	750 - 2900	150 - 1700	663 - 3150
(kg/t)	2.7 - 5.6**	22 - 137	-	3.93 - 25.4
SS (mg/l)	55 - 360	56 - 178	10 - 220	14 - 248
(kg/t)	0.1 - 0.7	1.6 - 8.0	-	0.39 - 1.45
pH	5.6 - 8.2	4.7 - 6.5	4.4 - 6.5	4.1 - 8.2 (Table 50)

* includes some juice production.

** in line with long term results.

7.3.3.2 Juices. Based on available data from one plant processing apples for juice production and processing concentrate for other juices, it has been possible to segregate these two types of commodities to determine their relative contributions to the effluent waste load. These data are presented in Table 76 in addition to the corresponding values from apple juice processing for United States plants.

Inspection of Table 76 shows that the unit waste loading for apple juice production in Canada is similar to that for the United States, bearing in mind that the latter data were for three processing plants only. The loading for processing concentrate is higher (12 - 35 kg/t). It should be noted that in the latter instance, the total production is relatively low and therefore the total contribution to the effluent waste loading in terms of kg/day would also be relatively low.

7.3.3.3 Pears. Few data are available from Canadian plants on pear processing; those available for the purposes of this study are presented in Table 77 with equivalent data taken from Table 9 for the purposes of comparison with U.S. operations. Inspection of Table 77 shows that for this plant, both the unit water consumption and the unit wastewater loading are within the range of values given for the United States plants.

7.3.3.4 Cherries. Based on the few data available for cherry processing, it is apparent from inspection of Table 78 that the two Canadian plants lie within the range of United States plants with respect to BOD_5 concentrations and loadings.

7.3.3.5 Corn. Data were not available from any Canadian operation which processed corn only; however, two plants processing corn during the plant survey also processed relatively small quantities of other commodities and therefore it was possible to draw meaningful conclusions from the raw wastewater data by assuming it to be essentially due to the corn operation. Pertinent data from the two Canadian plants and equivalent United States data are presented in Table 79.

The following conclusions can be drawn from inspection of Table 79:

1. Both Canadian plants are relatively small processors compared with United States operations.

TABLE 76. PRODUCTION RATES AND SCREENED WASTEWATER DATA - JUICES

PLANT NO.	APPLE JUICE 1*	CONCENTRATE 2*	TABLE 2 (APPLE JUICE)
Production (t/day)	200	3 - 10	38 - 107
Flow Volume (m ³ /t)	-	-	106 - 299
Flow Ratio (m ³ /t)	-	-	1.97 - 3.92
BOD ₅ (mg/l)	-	-	619 - 849
(kg/t)	3.1	12 - 35	1.60 - 2.54
SS (mg/l)	-	-	50 - 201
(kg/t)	-	-	0.16 0 0.47

* Raw feed basis.

TABLE 77. PRODUCTION RATES AND SCREENED WASTEWATER DATA - PEARS

PLANT NO.	1	TABLE 9
Production (t/day)	-	116 - 259
Flow Volume (m ³ /day)	-	900 - 5720
Flow Ratio (m ³ /t)	7.9	6.7 - 26.7
BOD ₅ (mg/l)	-	1340 - 2690
(kg/t)	30.0	12.9 - 53.1
SS (mg/l)	-	216 - 512
(kg/t)	-	2.0 - 14.4

TABLE 78. PRODUCTION RATES AND SCREENED WASTEWATER DATA - CHERRIES

PLANT NO.	1	2	TABLE 13
Production (t/day)	30 - 60	-	15 - 131
Flow Volume (m ³ /day)	-	-	129 - 320
Flow Ratio (m ³ /t)	-	-	6.6 - 24.9
BOD ₅ (mg/l)	-	740 - 1100	510 - 2200
(kg/t)	13 - 26	-	7.4 - 24.8
SS (mg/l)	-	-	45 - 117
(kg/t)	-	-	0.45 - 1.65
pH	-	4.6 - 6.1	5.2 - 7.9 (Table 50)

TABLE 79. PRODUCTION RATES AND SCREENED WASTEWATER DATA - CORN

PLANT NO.	1	2	TABLE 21
Production			
(t/day)	120 - 210*	160 - 210*	52 - 1290
Flow Volume			
(m ³ /day)	3180 - 5000	700 - 1040	290 - 6200
Flow Ratio			
(m ³ /t)	23.6 - 26.4	3.4 - 5.8	2.0 - 23
BOD ₅			
(mg/l)	1400	1200 - 1700	680 - 5280
(kg/t)	370	5.6 - 7.0	8.2 - 19.9
SS			
(mg/l)	160 - 490	310 - 370	180 - 1840
(kg/t)	3.9 - 12.9	5.3 - 7.2	3.9 - 8.0
pH	4.7 - 5.3	5.3 - 7.2	3.9 - 8.0

* includes up to 20% of other commodities.

2. Unit water consumption for Plant 1 is relatively high and that for Plant 2 is relatively low. It should be noted, however, that this flow ratio is on the total production rate which may include up to 20% of other commodities.
3. On the basis that the water consumption and BOD_5 loadings are at the high end of the range for Plant 1 when compared with those data for United States operations, it may be concluded that the high water consumption is resulting in higher than average wastewater loadings.

7.3.3.6 Beets. Data are presented in Table 80 for a Canadian plant processing beets; in addition, data based on nine U.S. beet processing operations are presented for the purposes of comparison. Inspection of Table 80 shows that the Canadian plant is relatively small but has a high unit water consumption ($34 - 42 \text{ m}^3/\text{t}$) compared with a range of $3.2 - 17.7 \text{ m}^3/\text{t}$ for the nine beet processing plants. Consequently the unit waste loadings in terms of BOD_5 and suspended solids are also higher than the range of the values for the nine United States plants.

7.3.3.7 Tomatoes. Data were made available for the plant survey from three Canadian plants processing tomatoes and these are compared with data from 17 United States operations in Table 81. Inspection of this table shows that Plant 3 is a large plant (4000 t/day compared with $400 - 2500 \text{ t/day}$ in the United States). In addition, Plant 3 has a relatively low water consumption and low unit waste loading in terms of BOD_5 and suspended solids. The average values reported for concentrations of these wastewater parameters confirm the low water consumption and low wastewater loadings.

Plant 1 exhibits relatively low unit waste loadings in terms of BOD_5 and suspended solids. In addition, Plant 2 exhibits concentrations of these wastewater parameters within the ranges for U.S. plants apart from one high value for BOD_5 . No production data were available for these two plants and therefore it was not possible to draw conclusions regarding unit wastewater loadings.

7.3.3.8 Jams and jellies. Data are presented in Table 82 for two plants processing jams and jellies. Inspection of these data show that the BOD_5 and suspended solids concentrations are within the ranges for the two United States operations given in Table 82 for the purposes of comparison.

TABLE 80. PRODUCTION RATES AND SCREENED WASTEWATER DATA - BEETS

PLANT NO.	3	TABLE 30
Production		
(t/day)	27 - 56	128 - 244
Flow Volume		
(m ³ /day)	1364 - 2270	526 - 3620
Flow Ratio		
(m ³ /t)	40.7 - 50.1	3.23 - 17.7
BOD ₅		
(mg/l)	1640 - 4940	1420 - 9700
(kg/t)	67 - 247	20 - 39.4
SS		
(mg/l)	400 - 675	370 - 4880
(kg/t)	16.4 - 33.8	5.0 - 18.5
pH	5.0	5.6 - 11.9 (Table 50)

TABLE 81. PRODUCTION RATES AND SCREENED WASTEWATER DATA - TOMATOES

PLANT NO.	1	2	3	TABLE 35
Production (t/day)	-	-	4000 - 4200	400 - 2500
Flow Volume (m ³ /day)	-	-	10200 - 11700	2700 - 26100
Flow Ratio (m ³ /t)	-	4.2	2.4 - 2.8	5.5 - 15.6
BOD ₅ (mg/l)	-	330 - 1950	500 - 610	300 - 780
(kg/t)	5.3	-	1.2 - 1.7	3.2 - 6.9
SS (mg/l)	-	70 - 500	290 - 360	280 - 1280
(kg/t)	2.3	-	0.7 - 1.0	2.9 - 13.2
pH	-	4.4 - 7.4	4.8 - 10.2	4.5 - 11.3 (Table 50)

TABLE 82. WASTEWATER DATA - JAMS AND JELLIES

PARAMETER	PLANT 1	PLANT 2	TABLE 43
BOD ₅ (mg/l)	40 - 380	340 - 1640	1150 - 4410
SS (mg/l)	10 - 150	20 - 133	394 - 711
pH	4.6 - 7.2	6.5 - 9.0	-

7.2.4 Conclusions

A number of relevant conclusions can be drawn from the data presented in Tables 72 - 82:

1. The unit wastewater loadings of BOD_5 and suspended solids from Canadian plants are generally within the ranges of values given for United States operations quoted in Section 3 of this report.
2. Based on data on BOD_5 , suspended solids, water flows and production rates, it is possible to draw conclusions regarding water use and effluent loadings for a specific plant for a specific operation. Comparison with the United States experience gives an indication of how Canadian plants operate with respect to water consumption, and whether or not water consumption could be decreased with a resultant decrease in raw wastewater hydraulic loadings, and possibly pollutant loadings.
3. Canadian plants processing the same commodity can be compared, provided they are approximately the same size.
4. The quality of the raw wastewater effluent from a given plant is primarily a function of the commodity being processed and is dependent upon the in-plant processing technology, discussed in Section 3 of this report.

7.3.5 Treated wastewater characteristics

End-of-pipe wastewater characteristics have been assessed for those Canadian plants taking part in the survey. Discussion and conclusions regarding the toxicity of treated plant effluent are contained in a separate subsection because of its importance.

Data obtained from the plant surveys and presented in Table 83 include removal efficiencies of the given treatment system in terms of percentages of BOD_5 and suspended solids for specific commodities processed, and final effluent characteristics in terms of BOD_5 , suspended solids, total phosphorus, TKN, ammonia and nitrate. Effluent parameters are expressed in terms of both concentrations (mg/l) and unit waste loadings (kg/t).

TABLE 83. FINAL EFFLUENT DATA FOR A NUMBER OF CANADIAN PLANTS

COMMODITY PLANT NO.	APPLE PRODUCTS		PEARS 1
	1	2	
Production (t/day)	170 - 310	11 - 20	-
Flow Volume (m ³ /day)	490 - 950	470 - 1900	-
Flow Ratio (m ³ /t)	4.2	42.9	7.9
Waste Treatment System	Aerated lagoon and clarifier	Aerated lagoon and settling basin	Spray irrigation holding lagoons
Final Effluent			
BOD ₅			
(mg/l)	50	290	1230
(kg/t)	0.21	12.4	-
SS			
(mg/l)	41	37	87
(kg/t)	0.17	1.6	-
P			
(mg/l)	0.97	10.6	2.54
(kg/t)	0.004	0.45	-
TKN			
(mg/l)	1.5	2.3	2.52
NH ₃			
(mg/l)	0.53	0.03	0.100
NO ₃			
(mg/l)	0.003	0.002	0.0028
Removal (%)			
BOD ₅	96	84	-
SS	80	68	-

TABLE 83. (Continued)

COMMODITY PLANT NO.	TOMATOES	
	1	2
Production (t/day)	-	4000 - 4200
Flow Volume (m ³ /day)	-	-
Flow Ratio (m ³ /t)	4.2	2.6
Waste Treatment System	Spray Irrigation	Aerated lagoon and clarifier
Final Effluent		
BOD ₅		
(mg/l)	85	9
(kg/t)	-	0.02
SS		
(mg/l)	38	10
(kg/t)	-	0.02
P		
(mg/l)	0.61	1.4
(kg/t)	-	0.003
TKN		
(mg/l)	1.3	1.3
NH ₃		
(mg/l)	1.3	9.6
NO ₃		
(mg/l)	0.11	0.8
Removal (%)		
BOD ₅	-	98
SS	-	97

TABLE 83. (Continued)

COMMODITY PLANT NO.	CORN 1	CORN 3
Production (t/day)	120 - 210*	-
Flow Volume (m ³ /day)	3180 - 5000	1250
Flow Ratio (m ³ /t)	4.6	-
Waste Treatment System	Spray irrigation	Aerated lagoons and clarifier
Final Effluent		
BOD ₅		
(mg/l)	73	559
(kg/t)	0.34	-
SS		
(mg/l)	5	2500
(kg/t)	0.02	-
P		
(mg/l)	0.08	15.4
(kg/t)	0.0004	-
TKN		
(mg/l)	0.40	54
NH ₃		
(mg/l)	0.12	0.061
NO ₃		
(mg/l)	0.0015	0.0017
Removal (%)		
BOD ₅	99	-
SS	99	-

* includes up to 20% other commodities.

A number of observations can be made by inspection of Table 83:

1. BOD₅ removal efficiencies are generally greater than 90% and result in a final effluent BOD₅ concentration of 50 - 100 mg/l and BOD₅ loadings up to 0.3 kg/t.

Plant 3 (apple products), although outside these ranges, operated at a relatively low production rate (11 - 20 t/day) and relatively high water usage (42.9 m³/t).

Data from Plant 1 (pears) and Plant 3 (corn) are not considered in this assessment since data on the impact of the holding lagoons on effluent quality were not available for the latter plant, and data on spray irrigation were not available for the former plant.

2. Suspended solids removal efficiencies generally range from 80 - 100%, to give a final effluent concentration of 5 - 50 mg/l and loadings up to 1.6 kg/t.
3. Concentrations of phosphorus generally range from 0.1 to 1.0 mg/l. The relatively high value for Plant 2 (apple products) may be associated with excessive use of this nutrient.
4. TKN values range from 0.4 to 2.3 mg/l.

7.4 Wastewater Toxicity

7.4.1 Bioassay testing

Wastewater from municipal sources and from many industrial sources contains materials and compounds which can cause mortality or adversely upset the biochemical functions of aquatic organisms. In a number of instances the toxicity is caused by inorganic salts which upset the hydrogen ion concentration (pH) of the aquatic habitat to such an extent that transfer of soluble materials and gases to the organism is inhibited. Toxicity can also result from a purely physical reaction to suspended or settleable particulates which wear down gill surfaces due to abrasive action or cover the habitat of benthic organisms.

A direct physical or chemical analytical procedure can be used to measure the level of these physical and inorganic sources of toxicity. Receiving water and effluent standards can then be set to protect fish and other

aquatic species. However, where complex organic compounds cause acute or sublethal toxicity, direct analytical techniques have not been developed for water quality control purposes.

In many wastewaters the specific compound causing toxicity is not definitely known. Bioassay testing is therefore utilized to detect the presence and concentration of toxic compounds in wastewater effluents. Any aquatic species which are sensitive to pollutants could be utilized as a test organism but fish have been chosen as the test animals for most toxicity work.

In Canada, the Fisheries Act is the federal legislation under which water pollution control regulations are promulgated and therefore the use of fish species for bioassay testing is appropriate. Although fish may not be the most pollution sensitive species in the adult form, they have the most direct value to the public as a food source or sporting activity.

Environment Canada has established levels of acute toxicity of wastewater effluents for pulp and paper and petroleum industry wastewaters by utilizing rainbow trout (*salmo gairdneri*) as the test organism. Rainbow trout are a particularly pollutant intolerant species compared with other species and considerable research has been carried out on their response to a wide range of pollutants.

The bioassay test involves observations of fish mortality to assess whether or not a particular waste can be discharged safely to a receiving water without causing death to indigenous fish species. Although there is not direct relationship between toxicity to rainbow trout and toxicity to other fish species, experience indicates that rainbow trout are a reliable indicator for most purposes. The standard toxicity testing procedure provides useful information on fish mortality; however, it cannot be used to evaluate sublethal effects such as interference with reproduction, destruction of food chain organisms, increase in avoidance response, and increase in susceptibility to disease.

7.4.2 Test method

The fish are exposed to different concentrations of the effluent at a specific temperature for predetermined lengths of time. The test conditions are specified with respect to weight of fish per litre of waste, number of fish per test, number of replicate tests, and the dissolved oxygen concentration to be maintained throughout the test.

Ideally the testing should be carried out in a flow through system. This technique ensures that waste materials generated by the fish do not accumulate during the test period and that depletion of toxic materials do not occur. Where a relationship between static testing (no continuous flow of diluted wastewater) and continuous bioassays can be developed, the simpler static test results are utilized for monitoring purposes. A description of the bioassay tests used in this study is provided in Appendix II. The toxicity levels utilized in reporting results were as follows:

Non Toxic - no mortality during the 96 hour test at any effluent concentration, including undiluted effluent.

Partly Toxic - a number of fish die in the tests, but less than half of them.

LC₅₀ 1 to 100% - half of the fish die in the 96 hour period in the concentration of effluent specified.

7.4.3 Plant raw wastewater

Inspection of Table 84 shows that all the screened raw wastewater sample sets from the fruit and vegetable processing plants taking part in the survey were toxic. Effluents from processing corn, tomatoes, apples, beets and a mixture of corn and other products showed 96 hr LC₅₀ values ranging from 12.5% to 36.0% by volume.

In many cases, death occurred very rapidly for the test fish: for example, for tomato wastes at 100% concentration, death occurred for all test fish within 15 minutes of the commencement of the test. The rapidity of the kill of test fish for all the toxic raw wastes is demonstrated in Table 85.

The chemical analyses of the toxic wastewaters are tabulated in Table 86. From inspection of these results it would appear that the toxicity is probably due to the high concentrations of suspended solids and organic material. The number of samples obtained during the study were not sufficient to state the cause of the toxicity with any statistical reliability.

The pH values of a number of the raw effluent samples were such that toxicity may have resulted from the hydrogen ion concentration (values less than 5.0 or greater than 9.5). However, other raw waste samples also exhibited similar values without the associated fish toxicity. It is interesting to note that corn wastes from two different processors were toxic in the raw

TABLE 84. FRUIT AND VEGETABLE INDUSTRY WASTEWATERS STATIC BIOASSAY TESTING

COMMODITY	NO. OF SAMPLES RAW	RAW SCREENED WASTE 96 Hr LC ₅₀	TREATED EFFLUENT 96 Hr LC ₅₀	EFFLUENT TREATMENT
Apples	2	24% 27%	Non-toxic (3) Partly toxic (1)	Aerated lagoon
Pears	-		Non-toxic Partly toxic	Spray irrigation Holding pond
Beets	1	12.5%	Non-toxic (2)	Spray irrigation Under drained
Corn, plums, jam	1	13%	Non-toxic (2)	Oxidation, Ditch and Settling
Corn, plums, jam, broccoli	1	17%	Non-toxic (2)	Oxidation, Ditch and Settling
Corn	1	18%	Partly toxic (2)	Spray irrigation
Corn	-		Partly toxic 71% 75% 100% Non-toxic	Aerated lagoon settling
Tomatoes	2	36% 13.5%	Non-toxic (2)	Trickling filter aerated lagoon settling
Tomatoes	-		Non-toxic (2)	Spray irrigation Under drained

Note: Number of analyses given in brackets.

TABLE 85. FRUIT AND VEGETABLE INDUSTRY RAW SCREENED WASTEWATER TOXICITY

COMMODITY	LC ₅₀ %	TEST CONC. %	% SURVIVAL AS A FUNCTION OF TIME (HOURS)						
			0.25	0.5	1.0	2.0	4.0	8.0	24.0
Tomatoes	36 13.5	100 56	0 100	0 90	0 90	0 20	0 10	0 10	0 0
Corn	18	56	80	30	0	0	0	0	0
Apples	24	56	100	80	60	30	0	0	0
Apples	27	56	100	60	10	0	0	0	0
Corn, Plums, Jam	13	100	-	-	0	0	0	0	0
Corn, Plums, Jam, Broccoli	17	50*	-	-	100	100	100	33	0
Beets	12.5	56	10	10	0	0	0	0	0

* three fish used in this test instead of ten.

TABLE 86. FRUIT AND VEGETABLE PROCESSING WASTES RAW SCREENED EFFLUENT
- CHEMICAL ANALYSES OF TOXIC SAMPLES

COMMODITY	BOD ₅	SS	pH	TOTAL P	TKN	NH ₃ N	NO ₃ N	NO ₂ N
Tomatoes	600 500	364 310	9.8 9.6	7.0 6.1	13.3 19.2	3.85 0.98	0.004 0.022	0.002 0.001
Corn	1400	488	4.65	3.0	14.88	1.0	-	-
Beets	1640	402	5.0	4.3	9.99	0.45	0.0044	0.0018
Apples	2080 1218	178 128	4.9 4.9	2.1 3.4	5.1 1.3	0.160 0.082	0.0012 0.0025	0.00 0.0060
Corn *	5108	580	5.3	3.15	1.85	1.45	0.0050	0.0240
Corn *	1182	320	6.5	4.5	0.50	0.001	0.0011	0.0001

* Dichlorobenzene added to screened wastes for odour control. Other commodities also processed.

NOTE: Units are in milligrams per litre except pH.

Symbols are defined in Appendix I.

screened state; the toxicity persisted in the biologically treated effluent from two of the processors (Table 84).

High oxygen demand and high suspended solids are suspected to be the cause of toxicity. Therefore it is very important that the test material be aerated throughout the duration of the bioassay tests to ensure that oxygen depletion is not the source of fish mortality.

An examination of the raw waste toxicity in terms of LC_{50} was also made at 24, 48, and 72 hours, shown in Table 87. It would appear that the 72 hour tests are in agreement with the 96 hour static bioassay test results for most cases. However, it would be advisable to utilize the 96 hour bioassay as the test duration in the future.

7.4.4 Toxicity of treated effluents

Eight of the 33 effluent samples examined during the study showed acute toxicity to rainbow trout (Table 84). Corn processing effluent was toxic at two of the three corn processing plants examined. At the plant where LC_{50} values greater than 50%, 71%, 75% and 100% were recorded, treatment consisted of an aerated lagoon with settling; raw screened effluent samples were not available from this plant and consequently toxicities could not be determined. Treatment of corn processing wastewaters exhibiting raw wastewater toxicity of 18.0 and 17.0% was successful in reducing the effluent toxicity to the point where less than 50% of the test fish died in full strength effluent.

Toxicity levels of less than 50% mortality in full strength effluent were also recorded for pear and apple processing effluents from spray irrigation - holding pond, and aerated lagoon treatment systems, respectively.

Examination of the chemical analyses of the toxic effluents (Table 88) and the corresponding raw waste chemical analysis shows that there is no firm relationship between toxicity and measured parameters, with the exception of BOD_5 and suspended solids concentrations. In the case of the corn processing wastes which exhibited toxicities ranging from greater than 50% to 100%, there were high total Kjeldahl nitrogen concentrations indicative of high protein content. It should be noted that wastewater effluents from the meat processing industry exhibiting high protein levels have been shown to exhibit toxicity.

TABLE 87. COMPARISON OF LC_{50} FOR VARIOUS STATIC TEST DURATIONS - RAW
SCREENED WASTEWATER

COMMODITY	24 HR	48 HR	72 HR	96 HR
Apples	-	24.0	24.0	24.0
	38.0	38.0	38.0	27.0
Beets	21.0	12.8	12.5	12.5
Corn	23.0	20.0	18.0	18.0
Corn *	16.0	13.0	12.5	12.5
	18.0	17.0	17.0	17.0
Tomatoes	45.0	36.0	36.0	36.0
Tomatoes	42.0	42.0	13.5	13.5

* includes other commodities.

NOTE: Units are effluent concentration in percent by volume.

TABLE 88. FRUIT AND VEGETABLE PROCESSING WASTES TREATED EFFLUENT CHEMICAL ANALYSES OF TOXIC SAMPLES

COMMODITY	BOD ₅	SS	pH	TOTAL P	TKN	NH ₃ N	NO ₃ N	NO ₂ N	LC ₅₀
Corn	415	1740	7.2	9.5	40.4	0.060	0.002	0.001	100%
	523	2440	7.0	26.0	47.8	0.039	0.003	0.001	71%
	864	3250	7.4	16.0	76.2	0.076	0.008	0.005	75%
	435	2820	7.5	10.0	52.4	0.067	0.001	0.002	50%
Corn	366	55	7.6	0.500	1.56	0.17	-	-	50%
	374	264	7.0	1.12	1.38	0.13	0.0013	0.007	50%
Apples	158	380	7.3	11.2	0.9	0.04	0.0012	0.0053	50%

NOTE: Units are in milligrams per litre except pH.

Symbols are defined in Appendix I.

In terms of the duration of the toxicity analysis, inspection of Table 89 for the toxicity of treated effluents from corn processing shows that a minimum of 72 to 96 hours is necessary to give reliable results for a static bioassay test.

7.4.5 Conclusions

A number of conclusions can be reached regarding the toxicity of effluents from the fruit and vegetable processing industry based on the limited amount of data obtained from the plant surveys.

1. Raw screened wastewaters from the following commodities demonstrate toxicity to rainbow trout, based on static 96 hour bioassays:
 - Tomatoes,
 - Corn,
 - Beets,
 - Apples,
 - Corn, plums, jam,
 - Corn, plums, broccoli, jam.
2. Since some toxicity persisted after biological treatment of pears, corn, and apple processing wastes, treatment to remove toxicity is necessary for fruit and vegetable wastewaters.
3. No definite chemical cause for toxicity could be determined from the limited testing program.
4. Corn processing wastes were the most toxic of the wastewater effluents examined. Since corn makes up a considerable percentage of Canadian vegetable processing, further investigation is required to determine the causes and methods to reduce the toxicity of corn processing effluents.
5. The high organic nitrogen content of the corn processing effluents may have contributed to effluent toxicity.
6. Although little information was available on process variables and design criteria, the aerated lagoons used for waste treatment were least successful in reducing effluent toxicity.
7. The toxicity level which could be specified in the regulations for fruit and vegetable processing wastewater effluents is no acute toxicity in full strength effluent.

TABLE 89. COMPARISON OF LC_{50} FOR VARIOUS STATIC TEST DURATIONS - TREATED
EFFLUENT - CORN

SAMPLE	24 HR	48 HR	72 HR	96 HR
1	Non-toxic	Partly toxic	100	100
2	Partly toxic	75	71	71
3	Non-toxic	Partly toxic	75	75
4	Non-toxic	Non-toxic	Non-toxic	Partly toxic
5	Non-toxic	Non-toxic	Non-toxic	Non-toxic

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Finally, the assistance of the associate consultants, Environmental Associates, Inc., is gratefully acknowledged.

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APPENDIX I

CONVERSION FACTORS

APPENDIX I

CONVERSION FACTORS

The following conversion factors were used in converting data available in English units to the metric system of units. A number of conversion factors are also included to show the relationship between the various units which may be used for a given parameter.

It should be noted that the multipliers give in Table 1 are for converting from English unit to S.I. Symbols are defined at the end of this Appendix in Table 2.

TABLE 1

CONVERSION FACTORS

ENGLISH UNIT	MULTIPLIER	S.I. UNIT
acre	4,046	m ²
acre	0.405	ha
acre-ft	1,234	m ³
cu ft	0.028	m ³
cu in	16.39	cm ³
cfm	0.02832	m ³ /min
cfs	1.70	m ³ /min
ft	0.3048	m
°F	0.5555 (°F - 32)	°C
gal (Imp)	0.004546	m ³
gal (US)	0.003785	m ³
gpd/sq ft (US)	0.0408	m ³ /day/m ²
gpm (Imp)	0.2728	m ³ /hr
gpm (US)	0.2271	m ³ /hr
in	2.54	cm
lb (mass)	0.4546	kg
lb/cu ft	16.02	kg/m ³
lb/1000 cu ft	16.02	g/m ³
lb/day/acre	0.112	g/day/m ²
lb/day/acre - ft	3.68	g/day/m ³
lb/day/cu ft	16.02	kg/day/m ³
lb/day/sq ft	4.880	g/day/m ²
lb/day/1000 sq ft	4880	g/day/m ²
lb/ton	0.5	kg/t
mgd (Imp)	4546	m ³ /day
mgd (US)	3,785	m ³ /day
sq ft	0.09290	m ²
ton	9072	kg
ton	0.9072	t

TABLE 2SYMBOL DEFINITION

SYMBOL	DEFINITION
cu ft	cubic feet
in	inch
cfm	cubic feet per minute
cfs	cubic feet per second
gpd	gallons per day
lb	pound
sq ft	square foot
ton	short ton
mgd	million gallons per day
m	metre
ha	hectare
cm	centimetre
kg	kilogramme
t	metric tonne

APPENDIX II

WASTEWATER PARAMETERS AND ANALYTICAL METHODS

APPENDIX II

WASTEWATER PARAMETERS AND ANALYTICAL METHODS

A brief discussion of the significance of the chemical, physical and biological parameters used in the study now follows. A description, and reference, for the analytical methods used to measure the parameter values is also included. The symbols used in the tables of data given in Fundamental Process Descriptions, Section 3, are given after the name of the parameter.

Five Day Biochemical Oxygen Demand (BOD_5)Significance

The BOD_5 test determines the amount of oxygen necessary for the biological oxidation of wastewaters, effluents and polluted waters over a five day period at 20°C . It is the most widely used parameter to characterize the "strength" of a waste. It is essential to the rational design of a wastewater treatment plant and is used in stream pollution work to determine the effect of an effluent on the dissolved oxygen levels of the receiving water body.

Analytical method

Reference: Standard Methods For the Examination of Water and Wastewater, 13th Edition, 1971, APHA, AWWA, WPCF, Washington, D.C. (Abbreviated: "Standard Methods, 1971").

Samples are mixed with air saturated water in volumes predetermined by the approximate strength of the waste. (This strength is known from values in the literature or from experience.) Samples are incubated in the absence of light at 20°C for a period of five days. Dissolved oxygen levels are measured initially and at the end of the five day period using the Winkler method with the Azide Modification technique.

Suspended Solids (SS)Significance

The suspended solids test is a measurement of the insoluble organic and inorganic material contained in a liquid sample. In terms of treatability the suspended solids level of untreated wastes is an indication of the

solids loading on a screen or primary clarifier. The efficiency of such unit processes can be evaluated by determining the suspended solids level both upstream and downstream of the device.

The suspended solids level of biologically treated wastes is a rough indicator of the amount of microorganism cells in the biological reaction tank or the effluent from the secondary clarifier.

Suspended solids levels are a significant effluent parameter since organic solids tend to settle out in receiving waters and cause oxygen depletion when they degrade. Inorganic solids can result in destruction of the habitat for benthic organisms.

Analytical method

- Reference: 1. Strickland, J.D.H. and Parsons, T.R. A Practical Handbook of Seawater Analysis, Bulletin No. 167 Fisheries Research Board of Canada, Ottawa, 1968.
2. Standard Methods, 1971.

A thoroughly mixed sample is filtered through a tared glass-fibre filter. The filter and retained solids are dried at 103°C for one hour, cooled to constant weight in a dessicator and reweighed. The suspended solids level is determined by determining the filter weight gain and dividing by the volume of sample used.

Hydrogen Ion Activity (pH)

Significance

pH is a measurement which expresses the intensity of the acid or alkaline condition of a solution. It has significance in biological wastewater treatment in that the hydrogen ion concentration must be controlled within rather narrow limits, 6.5 to 8.5, to optimize the bacteria which oxidize the waste. Higher forms of aquatic life in the receiving stream, including fish, also require the pH to be within specific limits to ensure survival.

Extremely acidic or alkaline pH conditions interfere with biochemical processes such as mass transfer across membranes and enzyme activity.

Analytical method

- Reference: Standard Methods, 1971.

A pH meter, with a combination glass electrode, is standardized with two buffer solutions of known pH. The pH of the sample is read from the meter while the sample is constantly stirred.

Total Phosphorus (Total P)

Significance

Phosphorus is an essential nutrient for most microorganisms including bacteria and algae. Most industrial wastes are deficient in phosphorus, that is they do not contain sufficient phosphorus to sustain the large populations of bacteria needed for biological treatment processes. However, discharging large quantities of phosphorus to natural water bodies enhances the growth potential for algae. In most cases, phosphorus has been identified as the limiting micronutrient in aquatic systems and for this reason maximum levels of phosphorus discharge have been set by a number of governmental regulatory agencies in recent years.

Analytical method

- Reference:
1. Standard Methods, 1971.
 2. Methods for Chemical Analysis of Water and Wastes, U.S. Environmental Protection Agency, 1971.

The total phosphate content of the sample includes all the orthophosphate, polyphosphates, and most organic phosphate compounds that are hydrolyzed to orthophosphate through mild acid hydrolysis. Polyphosphates and organic phosphates do not respond appreciably to the orthophosphate tests but are hydrolyzed to orthophosphate by boiling with acid. After digestion, total phosphate is measured quantitatively by the ascorbic acid or stannous chloride methods for orthophosphate determinations.

For samples with a total phosphate concentration of 0.01 to 6.0 mg/l, colour development with the above reagents is directly proportional to concentration and can be measured on a spectrophotometer at specific wavelengths.

Total Kjeldahl Nitrogen (TKN)

Significance

The Total Kjeldahl method measures most common organic nitrogen compounds found in wastewaters plus ammonia nitrogen. Most organic nitrogen

compounds characterized as TKN can be transformed by bacteria in biological treatment processes and the environment into ammonia. In this form they are available to most biological ecosystems to stimulate growth or cause further oxygen depletion upon conversion (see ammonia).

Analytical method

- References:
1. Standard Methods, 1971.
 2. Methods for Chemical Analysis of Water and Wastes, U.S. Environmental Protection Agency, 1971.

The sample is heated in the presence of concentrated sulphuric acid, potassium sulphate and mercuric sulphate and boiled until sulphur trioxide fumes are obtained. The solution becomes colourless or pale yellow. The residue is cooled, diluted and is made alkaline with hydroxide-thiosulphate solution. The ammonia is distilled and measured following Nesslerization by titration, or colourmetrically.

Ammonia Nitrogen ($\text{NH}_3\text{-N}$)

Significance

Nitrogen in the ammonia form is an essential nutrient for a wide variety of bacteria and algae. Many industrial wastes are deficient in nitrogen, and ammonia is added to stimulate biological activity necessary for treatment processes. In the receiving stream some bacterial species use ammonia as an energy source and form nitrites which in turn degrade to form nitrates. Oxygen is used in these biological processes and ammonia therefore represents an additional oxygen demand on a receiving water. Ammonia can be toxic to fish at levels in the neighbourhood of 3 mg/l.

Analytical method

- Reference: Solorzano, L. Determination of Ammonia in Natural Waters By the Phenol Hypochlorite Method. *Limnology and Oceanography* 14 (5): 799-801, 1969.

The blue colour of indophenol obtained by the reaction at high pH of ammonia, phenol, and hypochlorite is measured spectrophotometrically. This method eliminates interference due to precipitates by complexing magnesium and calcium with sodium citrate.

Nitrate Nitrogen ($\text{NO}_3\text{-N}$)

Significance

A high level of nitrate in treated wastewater often indicates that wastewater treatment plant is underloaded. A highly nitrified effluent occurs through the activity of nitrifying bacteria which convert ammonia to nitrate thus decreasing the oxygen depleting potential of discharged nitrogen compounds.

Analytical method

Reference: "A Practical Handbook of Seawater Analysis",
Strickland and Parsons, 1968.

The nitrate in the sample is reduced almost quantitatively to nitrite when it passes through a column containing cadmium filings loosely coated with metallic copper. The nitrite thus produced is measured by the method outlined for reactive nitrite. A correction may be made for any nitrite initially present in the sample by subtracting nitrite nitrogen from the total nitrate plus nitrite.

Nitrite Nitrogen ($\text{NO}_2\text{-N}$)

Significance

In wastewater effluents, nitrite is usually present in very small concentrations, less than 0.1 mg/l, since the conversion rate of nitrite to nitrate is rapid. However, its concentration must be determined in order to measure accurately the level of nitrate present.

Analytical method

Reference: "A Practical Handbook of Seawater Analysis",
Strickland and Parsons, 1968.

The nitrite is reacted with sulphanilamide in an acid solution. The resulting diazo compound reacts with naphthylethylene diamine reagent and forms a highly coloured azo dye, the absorbance of which is measured spectrophotometrically.

Bioassay (LC_{50})

Significance

Complex organic compounds, inorganics, and various solid materials can all be acutely toxic to aquatic life. Most wastewaters are toxic to

aquatic organisms to some degree but at the present level of technology, toxicity is measured on a routine basis for regulatory purposes only on fish.

Selected fish species are exposed to varying concentrations of effluent at specific temperatures and for predetermined lengths of time in bioassay tests.

When these tests using wastewater prove acutely toxic, this information is used to determine whether or not the given waste can be discharged to a receiving water without causing direct mortality to indigenous fish species. Some effluents, although not directly toxic in 96 hour tests, may produce undesirable effects at sublethal concentrations.

Different kinds of fish and other aquatic organisms are not equally susceptible to toxic substances. Laboratory raised, disease-free rainbow trout are normally used as the test animal to permit comparison with other toxicity values. When it has been adequately determined through bioassay tests that a particular effluent may be injurious to aquatic life, appropriate treatment or alternate disposal methods can be employed to negate the effect.

Analytical method

Reference: 1. Standard Methods, 1971

2. Doudoroff, P. Bioassay Methods For the Evaluation of Acute Toxicity of Industrial Wastes to Fish. Sewage and Industrial Wastes 23(11): 1380-1397, 1951.

Bioassay samples are obtained from the field, shipped to the testing laboratory and set up for the experimental procedure in as short a time as possible (less than 48 hours) after the sample is taken. Ten rainbow trout (*Salmo gairdneri* Richardson) are placed in each of six different concentrations of effluent water (usually 100%, 56%, 32%, 18%, 10% and 0% - control) and monitored for mortality at set intervals for 96 hours. Plotting the mortality at each concentration over time enables an extrapolated estimate of the 96 hour LC_{50} to be made.

LC_{50} is defined as the concentration of effluent required to produce 50% mortality in a 96 hour test period. A number of different types

of results may be obtained:

1. Non-toxic - mortality during the 96 hour test at any effluent concentration including undiluted effluent.
2. Partly toxic - a number of fish die in undiluted effluent but less than half of them.
3. 1-100% - half the fish die in the 96 hour period in the concentration of effluent specified.

